Joint Transportation Research Program

JTRP

FHWA/IN/JTRP-98/19

Final Report

The Development of a Speed Monitoring Program for Indiana

Darren L. Jorgenson
Kumares C. Sinha

April 2000

Indiana Department of Transportation

Purdue University

Final Report

FHWA/IN/JTRP-98/19

THE DEVELOPMENT OF A SPEED MONITORING PROGRAM FOR INDIANA

Darren L. Jorgenson
Graduate Research Assistant

and

Kumares C. Sinha
Olson Distinguished Professor

School of Civil Engineering
Purdue University

Joint Transportation Research Program
Project No: C-36-10F
File No: 8-3-6

Prepared in Cooperation with the
Indiana Department of Transportation and
the U.S. Department of Transportation
Federal Highway Administration

Purdue University
West Lafayette, Indiana
April 2000

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JTRP-98/19		

4. Title and Subtitle	5. Report Date
The Development of a Speed Monitoring Program for Indiana Supplemental Report	April 2000
	6. Performing Organization Code
7. Author(s) Darren Jorgenson and Kumares Sinha	8. Performing Organization Report No. FHWA/IN/JTRP-98/19
9. Performing Organization Name and Address Joint Transportation Research Program 1284 Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284	10. Work Unit No.
	11. Contract or Grant No. SPR-2150
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.

16. Abstract

From the passage of the National Maximum Speed Limit (NMSL) of 55 mph in 1974 through its repeal in 1995 speed monitoring programs have been mandated by the federal government. The speed-monitoring program was primarily intended to provide reliable data to be included as a part of the State's annual certification in order to be approved for Federal Aid highway projects. The repeal of the NMSL in 1995 not only authorized states to set their own speed limits, it also allowed states to develop their own speed monitoring programs. The goal of this research is to provide the framework for a speed-monitoring program to meet the needs of agencies and organizations that use speed-monitoring data in the State of Indiana. A proposed speed monitoring plan is developed which distributes speed monitoring stations to highway classes according to three primary criteria: spatial distribution, crash distribution, and distribution of daily vehicle miles traveled. The proposed speed-monitoring program will utilize 38 existing speed, weigh-in-motion, and automated traffic recording stations. The stations will be monitored four times a year for a 24-hour period. Furthermore, the proposed program will monitor speeds based on vehicle length. It is the recommendation of this research that Indiana phase in the proposed speed-monitoring plan developed in the present research, during the 1999 calendar year. The implementation should include a visual inspection of all the WIM, ATR, and speed monitoring stations listed in Appendix A to ensure they are still capable of monitoring speeds by vehicle class and travel direction. If any problems should arise with the existing stations, that station should be substituted for another station within that district and highway class.

This report is a supplemental report to the main report of the study, FHWA/IN/JTRP-99/14, which will be published in December 1999.

.

17. Key Words	18. Distribution Statement
Maximum Speed Limit, state highway network, Indiana, safety, productivity	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	80	

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 INTRODUCTION

1.1 Background Information

The Joint Transportation Research Program has conducted annual speed studies for the Indiana Department of Transportation (INDOT) since 1956. The early studies were of free flowing traffic on rural highways and were for the purpose of evaluating speed trends for the state.

In 1974, the U.S. Congress made the National Maximum Speed Limit (NMSL), (initially a temporary energy conservation measure) of 55-mph permanent. The Federal-Aid Amendments of the 1974 Highway Act made annual state enforcement certification a prerequisite for approval of Federal-Aid highway projects. Summary data from state speed monitoring programs were a part of these annual certifications. In order to keep monitoring practices consistent in all states, state speed-monitoring programs would have had to follow a sequence of Federal procedural manuals.

As time went on, the Federal government felt that public compliance with the National Maximum Speed Limit worsened somewhat. In response, Congress passed the Highway Safety Act of 1978, which provided for both withholding Federal-Aid highway funds and awarding incentive grants based on annual speed compliance data. The incentive grant program was later discontinued. The decision on penalties was based on the fraction of all vehicles exceeding 55mph on roads and streets posted at 55 mph.

On April 2, 1987, the Federal-Aid Highway Act of 1987 was enacted. The National Traffic Safety Administration (NHTSA) amended Section 174, 23 U.S.C. 154 as mandated by the Act. This amendment gave the states the authority to increase,

without the loss of Federal-Aid-funds, the maximum speed limit to no more than 65 mph on Interstate Systems located outside an urbanized area of 50,000 (population) or more because Rural Interstate highways had the lowest level of compliance with the NMSL, but they also had among the lowest fatality rates. This amendment stated: "states may raise speed limits on eligible highway sections immediately without waiting for the end of the fiscal year". For Indiana, the effective date for the change from 55 mph to 65 mph on eligible Rural Interstate sections was June 1, 1987.

On November 28, 1995, Federal legislation was signed into law that repealed the National Maximum Speed Limits, ending two-decades of mandates. Effective on December 8, 1995, states were again allowed to set their own speed limits and speed monitoring policies. It is this legislation that is the motivation behind the present study, to develop a new speed-monitoring program for Indiana.

1.2 Measurement of Traffic Speed

1.2.1 Background

Speed is one of the three principal parameters used in describing the state of a given traffic stream, with volume and density being the other two. It is defined as a rate of motion in distance per unit time, the inverse of the time taken by a vehicle to traverse a given distance. Vehicle speeds vary both in time and in space and can be measured singularly at a point, or can be averaged over a relatively long section of street or highway between an origin and destination. In a moving traffic stream, each vehicle travels at a different speed. Thus, the traffic stream does not have a single characteristic speed but rather a distribution of individual vehicle speeds.

From a distribution of discrete vehicle speeds, a number of "average" or "typical" values may be used to characterize the traffic stream as a whole. The mean speeds

obtained from the two types of distributions, time and space, are distinct and are called the "time-mean speed" and "space-mean speed" respectively. In essence, time mean speed is a point measure, while space-mean speed is a measure relating to a length of highway or lane.

1.2.2 Spot Speed

Spot speeds are speeds measured as vehicles pass a point on the road. Spot speed data are generally collected using one of two methods (McShane and Roess 1990). The first is by observing vehicles passing a fixed point in the road, by use of a radar device or other point detector, and directly observing speed. The second method is to observe vehicles passing a fixed point in the road, employing a short "trap" – generally consisting of a pair of inductive loop detectors a known distance apart, and observing travel time over the trap. Spot speeds are determined by dividing the trap length by the travel time. A wayside computer can record the speed data for a given time interval and provide a summary report.

A series of spot speed measurements at a given location may be represented simply by the time mean speed, but the information so revealed is confined to the central tendency of the data. Of greater interest are the distribution, the range and the dispersion of the speeds in addition to the mean. In order to fully benefit from this measured information, standard statistical methods of analysis must be adopted to describe the speed data. The statistical analysis methods utilize the frequency and cumulative frequency curves.

The frequency curve, shown in Figure 1.1, is obtained by plotting the percentage of vehicles traveling in a given speed range versus the given speed range. The information revealed by said curve is the modal speed and the pace. The modal speed is the speed occurring most frequently and is the peak of the frequency curve. The curve is also

useful for determining the pace of the vehicles where the pace is the speed range, for some nominal increment of speed, which contains the most vehicles. The cumulative frequency curve, as shown in Figure 1.2, is used for determining the number of vehicles traveling above or below a given speed. The median speed, another measure of central tendency, is that speed below which 50 percent of the vehicles are moving. Percentile speeds (i.e. speeds below which specified percentages of vehicles are traveling) are also readily revealed.

1.2.3 Space Speeds

Space speed studies are typically performed by the license plate or the test car technique (ITE 1976). The license plate technique involves a two-person team of observer and recorder for each direction of travel at both the start and the end of the study route to record section travel times. In the test car method a test car will run over a section of road, recording section travel times for each of several runs. With this method the test car will become a "typical" vehicle in the traffic stream by floating with the stream, meaning it passes as many cars as pass it. It will then be assumed to be running at the space speed.

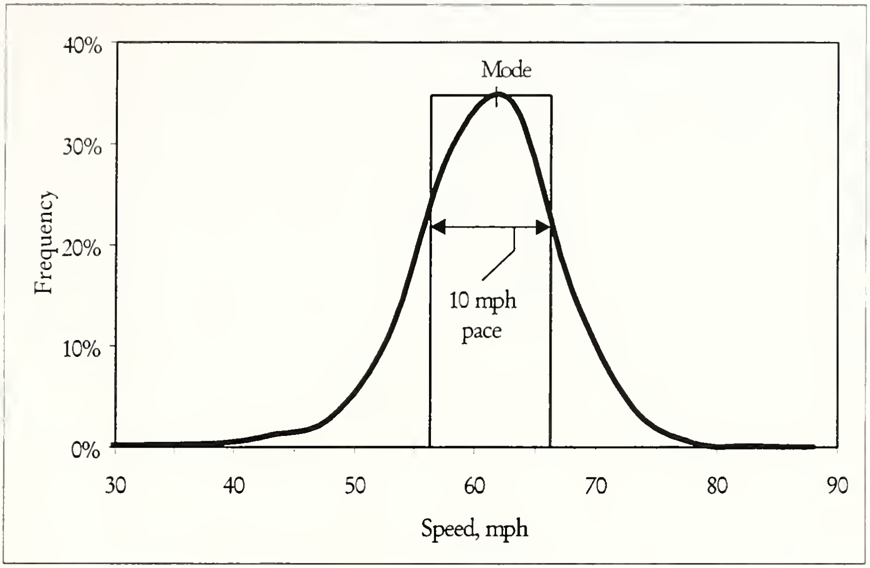


Figure 1.1. Frequency Curve

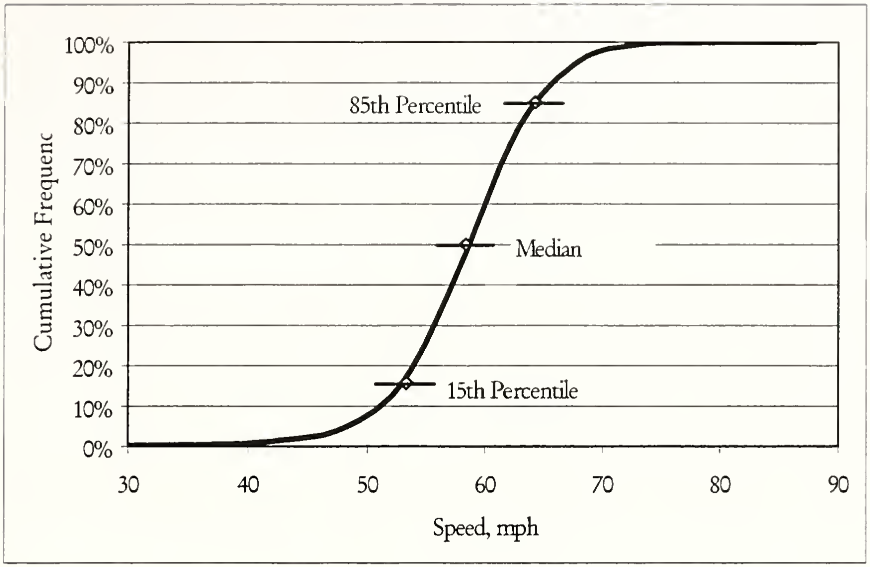


Figure 1.2. Cumulative Frequency Curve

Average travel speed and average running speed are two forms of space mean speed that are frequently used as traffic engineering measures. Travel time is defined as the total time to traverse a given highway segment. Running time is the total time during which the vehicles is in motion while traversing a given highway segment. The difference between the two is that running time does not include stopped delays, while travel time does.

Space speeds are used in capacity relations, such as between flow, density, and speed. Thus, space mean speed is the proper measure of the performance of a highway, and maps of facility performance should be in terms of space mean speed. While it is noted that space speeds play an important role in determining service levels, the most common form of speed data used in traffic analysis is obtained through spot speed studies.

1.3 Use of Speed Monitoring Data

The objective in the design of any engineered facility to be used by the public is to satisfy the demands for service in the safest and most economical manner. As such, speed is one of the most important factors to the traveler in selecting alternate routes or transportation modes. The value of a transportation facility in carrying people and goods is judged by its convenience and economy, which are directly related to its speed.

At the same time, speed is related to travel safety. The National Crash Severity Study (NCSS), an investigation of approximately 10,000 crashes from 1977 to 1979, revealed that the possibility of fatality increases dramatically as the change in velocity during the collision increases (Flora 1982). From this study it was shown that a driver crashing with a change in velocity of 50 mph is twice as likely to be killed as one crashing with a change in velocity of 40 mph.

Vehicle speeds contribute to crash probability, particularly the variability in speeds on the same segment of highway. Speed variance, a measure of the relative distribution

of travel speeds on a roadway, relates to crash frequency in that a greater variance in speed between vehicles correlates with a greater frequency of crashes, especially crashes involving two or more vehicles (Solomon 1964). A wider variability in speeds increases the frequency of motorists passing one another, which in turn increases the opportunities for multi-vehicle crashes to occur. Clearly, vehicles traveling the same speed in the same direction do not overtake one another; therefore, they cannot collide as long as the same speed is maintained.

An important determinant of traffic safety is effective speed enforcement. The first modern speed-enforcement technique, introduced in 1903 by New York City Police Commissioner William McAdoo, consisted of three dummy tree trunks set up at one-mile intervals along Hudson Drive in New York City (Jarman 1956). When a car sped past the first station, a policeman – stationed inside the fake tree with a stopwatch and telephone– would telephone the exact time to the officer in the next tree. The second officer set his watch accordingly. When the car went by his post, he computed its speed for the mile. If this was above the limit, he telephoned the policeman in the third tree, who lowered the pole across the road and stopped the car. While the enforcement techniques have changed over the years, the principal reasons for controlling vehicle speeds, protection of life and property against the hazards of highway travel and efficient use of street and highway systems, have not.

Speed monitoring data allow agencies to set up enforcement strategies, which will reduce speeds and, consequently, increase safety. Vaa (1997) conducted a field experiment in which a 35-km long stretch of road was subjected to an increase in police enforcement. Speed measurements were done in 60 and 80 km/h speed-limit zones before, during and after enforcement withdrawal, and compared to another stretch of road. Average speeds were reduced in both speed limit zones and for all times of day. For some time intervals, the average speed and the percentage of speeding drivers were reduced for several weeks of the after-period, demonstrating a time-halo effect of eight

weeks. The time-halo effect is defined as the length of time during which the effect of enforcement is still present after police activity has been withdrawn. The distance-halo effect is the number of miles from the enforcement site– be it downstream or upstream – within which the effect is maintained.

1.4 Scope and Objectives of Present Study

The purpose of the present study is to develop a speed-monitoring program to meet the needs of agencies that use speed-monitoring data within the State of Indiana. The present study will examine the existing FHWA-mandated speed-monitoring program and evaluate the core components of the program. The core components that will be evaluated in the present study are the number of monitoring sessions per year, length of monitoring period for individual sampling sessions, and the minimum number of statewide sampling locations. In addition, the present study will evaluate the need for monitoring speed by vehicle length and speed by direction of travel. Also, a methodology will be developed for allocating speed-monitoring stations by highway class based on given criteria. Finally, the location of speed monitoring stations will be determined utilizing as many of the existing stations as possible in terms of statistical requirements.

The present study is warranted for a number of reasons. First, the existing program was designed to meet Federal requirements and did not necessarily address the particular needs of state agencies. Second, speed-monitoring stations were distributed to highway classes based solely on daily vehicle miles traveled (DVMT). Finally, the existing program did not account for geographic gaps that occurred between stations where no monitoring occurred. In the following chapters each of these concerns will be addressed.

1.5 Organization of Report

Following this introductory chapter where the role of speed monitoring and the need for the present study were discussed, the remainder of the report will be presented as follows. Chapter Two provides a discussion on the existing FHWA-mandated speed-monitoring program in Indiana, as well as a discussion on the current speed-monitoring practices in the other 49 states. Chapter Three identifies the speed monitoring needs in Indiana. This chapter also provides overall strategic framework of the proposed speed-monitoring plan. Chapter Four presents the proposed speed-monitoring program along with a comparison to the existing program. Chapter Five gives conclusions and recommendations.

CHAPTER 2 REVIEW OF CURRENT PRACTICES

2.1 Evolution of Speed Monitoring in Indiana

The Joint Transportation Research Program (JTRP), formerly known as the Joint Highway Research Project (JHRP), has conducted annual speed studies for INDOT since 1956. The early studies were of free flowing traffic on rural highways and were for the purpose of evaluating speed trends. During this history, JTRP established twelve rural speed stations where speeds were measured each summer. Four stations each were located on Rural Interstates, other 4-lane divided and 2-lane state highways in Indiana where the State maximum speed limit applied. Two Urban Interstate speed stations were also monitored in this study.

In 1973, Congress established a National Maximum Speed Limit (NMSL) of 55 mph, initially as a temporary energy conservation measure. In 1974, congress made the national maximum speed limit permanent. The Federal-Aid Amendments of 1974 made annual state enforcement certification a prerequisite for approval of Federal-aid highway projects. Summary data from state speed monitoring programs were a part of these annual certifications. These state speed-monitoring programs had to follow a sequence of Federal procedural manuals.

The first, "Procedural Guide for Speed Monitoring", issued in September 1975 (U.S. DOT 1975), provided guidelines for monitoring speeds to determine the level of motorist compliance with the speed limit. Data were collected on level, tangent highway sections under "free-flow" conditions. The original speed monitoring procedures were designed to produce statistics for each of five highway types in a state.

From that, it was decided to develop statewide statistics representative of conditions on all highway types. Methods for calculating statewide statistics varied among the states, making the value of state-to-state comparisons questionable.

Slowly declining compliance with the 55-mph speed limit and increasing crash and fatality rates prompted the U.S. Department of Transportation (DOT) to recommend and the Congress to approve significant changes in the speed limit legislation in 1978. The Highway Safety Act of 1978 provided for both withholding Federal-aid highway funds and awarding incentive grants based on speed compliance data submitted annually. The major data requirement in each state was now an estimate of the percent of motor vehicles exceeding 55 mph, which is representative of travel on roads and streets having legal speed limits of 55 mph. "Interim Speed Monitoring Procedures," issued in December 1978 (U.S. DOT 1978), contained instructions for collecting and reporting speed information on these roads and streets for fiscal years 1979 and 1980.

The 1978 legislation necessitated major changes from earlier monitoring programs. New monitoring procedures were presented in that manual. First, a requirement that a statewide figure for percent of motor vehicles exceeding 55 mph be developed which would represent statewide travel on all systems of highways with limits of 55 mph, not just for individual systems. Second, free-flow would no longer be the only condition monitored. Speed statistics had to be representative of all travel; thus, all vehicles passing a monitoring station during the observation period were measured, regardless of the traffic conditions. In addition, speeds could be monitored on highway sections that were not necessarily level or tangent. Finally, speed monitoring would not need to be conducted under rather ideal weather conditions. Although monitoring during snow conditions was discouraged, wet, damp or rainy weather would no longer be disqualifying.

Further changes were made in the "Speed Monitoring Program Procedural Manual" (SMPPM), issued in May 1980 (U.S. DOT 1980). A few of the important points are

discussed. First, sampling sessions were to be 24 hours long in order to account for varying traffic conditions affecting speeds, within each day. This would ensure that the within-cluster variation would now allow a reduction of the number of locations required, even if much longer periods were used. This, in turn, would minimize costs in terms of the combination of sampling locations required and the need for equipment, facilitate scheduling of data collection, and allow aggregation of estimates by day of week and month.

In addition, highways were stratified into 6 categories based on Federal Highway Administration (FHWA) classifications, instead of the 5 categories based on geometry as previously. Within a category, locations were picked using simple random sampling with probabilities proportional to mileage. Sessions were allocated among highway categories based on the statewide DVMT subject to the 55-mph speed limit in each highway category. The use of unmanned data collection equipment, which were inductive loop detectors, for speed monitoring was now required. Also, the term "posted" was defined to exclude roads which the FHWA defined to be "local" and any unpaved roads, but to include other roads and streets, state highways or not.

The definitions of control and standard locations were changed. Control locations were monitored once each quarter and standard locations once each year. All sessions were to be evenly distributed throughout the year. The requirement to move certain locations annually ceased.

The target sampling accuracy of the annual statewide value of percent of DVMT traveled at over 55 mph was 2.0 percent at a 95 percent confidence level. The number of sampling locations was intended to be established as the greater of the numbers needed to meet the target sampling accuracy and the daily vehicle miles traveled (DVMT) subject to the 55-mph divided by 2 million. In Indiana, the number of sampling locations was 35. A corrected procedure would have required approximately 240

stations; however, FHWA never required an increase in the original number of sampling locations.

The SMPPM necessitated several changes in Indiana's speed monitoring program and a new set of monitoring locations was selected. Since the new procedures required random sampling, the set of locations in Indiana's historical monitoring program could not be included. The results of the historical program were then reported separately. The thirty five locations for the study required for certification were selected according to the procedures outlined in the SMPPM. Some locations were then moved, either temporarily or permanently.

In April 1987, the Federal-Aid Highway Act of 1987 (Act) was enacted. The National Traffic Safety Administration (NHTSA) amended Section 174, 23 U.S.C. 154 as mandated by the Act. This amendment gave the states the authority to increase, without the loss of Federal-aid funds, the maximum speed limit to no more than 65 mph on Interstate Systems located outside an urbanized area of 50,000 (population) or more. This amendment stated that states may raise speed limits on eligible highway sections immediately without waiting for the end of the fiscal year. For Indiana, the effective date for the change from 55 mph to 65 mph on eligible Rural Interstate sections was June 1, 1987.

The Act also said that "any state choosing to increase the speed limit from 55 mph would have to adjust the speed sampling and analysis plan which was in effect for the fiscal year in which the limit is raised". A memorandum (HTO-31, 8 June 1987) distributed by the FHWA advised states that elected to increase the speed limit on eligible sections of Rural Interstates, that DVMT represented by the mileage on which the speed limit was raised above 55 mph would be excluded from the calculation of FY 1987 55 mph speed limit compliance statistics. For Indiana, no Rural Interstate locations were monitored from June 1 to September 30, 1987.

The DVMT weighting factors were adjusted, due to the exclusion of all historical Rural Interstate locations that were re-posted to 65 mph. These factors were re-distributed among the six highway classifications as applicable for 1987 and 1988. Even though a process of re-distribution of DVMT weighting factors excluded the requirement of monitoring and reporting statistics for Rural Interstates, the same number of locations would continue to be distributed among the remaining functional groupings in the same proportion as previously specified – although no specified reason for this requirement was given. Therefore, 35 monitoring locations were still required in Indiana.

The memorandum (HTO-31, 8 June 1987) also stated that if the DVMT weighting factor for the Rural Interstate functional class should "drop to 0.0100 (1%) or less, that grouping should be dropped for the calculation process completely". For Indiana, the DVMT weighting factor was greater than 1%; therefore, two new 55 mph Rural Interstate sections had to be selected for monitoring speeds during most of the 1988 Speed Year. As more Rural Interstate areas were re-posted to 65 mph during 1988, the DVMT weighting factors dropped to less than 1%. By the end of the 1988 Speed Year, Rural Interstate highways in Indiana were exempt from compliance with the 55-mph national maximum speed limit. Statistical results of speed monitoring on Indiana Rural Interstate highways were reported separately through December of 1990, at which time the monitoring of Rural Interstate highways was discontinued.

On May 5, 1989, an FHWA memorandum (HEO-05) revised the interpretation concerning the location of the 55/65-mph speed zone limits. This revision stated that a state could now locate the transition point in the vicinity of the first interchange within the urbanized boundary, rather than at the urbanized boundary. For Indiana, the completion of revision of the 55/65 mph termini location to the nearest interchange in the urbanized zone, occurred during August 1989. Revised weighting factors were issued in October of 1989 for use in calculating statistical summaries for the 1990 Speed

Year. These new DVMT values required a major alteration in the number of types of highway classes to be monitored during 1990.

In December of 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) was signed into law. FHWA and NHTSA subsequently published modifications to 23 CFR Parts 659 and 1260, governing the National Maximum Speed Limit (NMSL). The revised procedures to 23 CFR part 1260 established speed limit compliance requirements on both, 55 mph and 65 mph roads. This statute assigned greater weight for violations of the applicable speed limits in proportion to the amount by which the speed of the motor vehicle exceeds the speed limit. Additionally, the ISTEA compliance formula was more closely tied to the relative risk of fatality and a measure of crash severity.

New data collection and reporting procedures, relative to this law, became effective October 1, 1994 (Federal Register 1993). This regulation required a compliance score from annual speed monitoring summaries, and was weighted toward the amount motorist speeds exceeded the posted speed limit. Compliance scores from three consecutive years were intended to comprise an average score, which would then become a state's annual compliance score. A maximum score was established for all states meeting criteria based upon total miles of each highway class. For Indiana, a maximum score was determined to be 210, and exceeding either score would result in non-compliance with the NMSL. Non-compliance sanctions amounting to 1.5% of Federal-Aid construction project funds were to be diverted to state highway safety programs at the end of each Speed Year, if applicable.

Changes to the "Speed Monitoring Program Procedural Manual (SMPPM)" were again published in 1992 (U.S. DOT 1992). The 1992 SMPPM revised the procedures, categories, and number of speed monitoring sites to be selected. Speed monitoring stations were required to be randomly selected from five-mile long Highway Performance Monitoring System (HPMS) segments within a highway category, rather

than using DVMT statistics, as previously. Highway types were divided into three main categories: freeways posted at 55 mph, freeways posted at 65 mph, and non-freeways posted at 55 mph.

Tables for each highway category in the manual determined the minimum number of monitoring stations in each highway category. The actual number of stations required was proportional to the number of five-mile Highway Performance Monitoring System (HPMS) segments in each category. The tables assumed a 7.5 percent level of precision, and were the minimum necessary in each category to meet the precision requirement for SMPPM guidelines. The SMPPM also required the number of monitoring stations to be a number no less than 30 percent higher than the maximum number of monitoring stations under the previous program. The reason for the increase was to account for the monitoring of Rural Interstate segments. For Indiana, the number of required statewide speed monitoring sites rose from 35 to 46.

Further changes were required in the site selection process. Since all previous speed monitoring stations had already been randomly selected, based upon previous SMPPM guidelines, many were kept for the new certification program. Of the original 35 locations monitored, 24 HPMS sites were retained. Using the 1992 SMPPM guidelines, 22 new speed-monitoring sites were chosen from the Indiana State HPMS data base. This most recent station layout is shown as Figure 2.1.

On November 28, 1995, Federal legislation was signed into law that repealed the National Maximum Speed Limits, ending two-decades of mandates. Effective December 8, 1995, states were again allowed to set their own speed limits and speed monitoring policies.

2.2 Speed Monitoring Practices in Other States

2.2.1 Background

Prior to the repeal of the NMSL in 1995 all states were required to conform to a Federally mandated speed-monitoring program as described in the previous section. Following the NMSL repeal, however, states were allowed to set their own speed monitoring policies. In the present study, information was gathered on the speed monitoring practices of other states, with particular interest in how the procedures changed following the NMSL repeal.

With this in mind a survey was conducted to examine the characteristics of individual states' speed monitoring programs. The issues included whether a reduction or increase in the number of speed monitoring stations occurred, changes in the distribution criteria, changes in the total number of sampling stations, and the extent and duration of sampling sessions. The information gathered from this survey was presented to the study advisory committee formed for the present project, in order to develop appropriate parameters for revising the speed monitoring program in Indiana.

2.2.2 Survey Development

The questionnaire that was used for this survey evolved from suggestions provided by the members of the study advisory committee. The states were asked to provide general information on the characteristics of their current speed monitoring programs. To this extent a state was asked yes or no if its speed monitoring program classified vehicles, if they monitored speed in both directions of travel, how often a year they measured speeds (i.e. daily, monthly, quarterly, semi-annually, annually, as needed), and how long individual monitoring sessions were (i.e. 24 hours, 48 hours, 72 hours, continuous).

The state was asked to provide the number of speed monitoring stations it operates before and after the NMSL repeal. From this question it could be inferred whether or not a state continued to monitor speeds and if they increased or decreased the number of monitoring stations. The states were also asked to provide specific information on why and where they placed their speed monitoring stations. The state was asked to mark the criteria for selection of the station locations for their current program (for example, uniform distribution throughout the state, based on speed limits, simple random selection, where existing stations are, random selection by volume, random selection by highway class, and crash rates). It was not necessary to ask the state to mark the selection criteria prior to the NMSL repeal as they were mandated by the FHWA to be random selection by volume. Finally, the state was asked to give a breakdown on the location of the speed monitoring stations before and after the NMSL repeal (i.e. Rural Interstates, Urban Interstates, Rural U.S. Road, Urban U.S. Road, Rural State Road, and Urban State Road).

2.2.3 Survey Administration

The survey mailing list was provided by the FHWA, giving contact names and addresses for sending the questionnaire. The first step of the survey process was placing a courtesy call to the individuals in the list. This was to let them know that they would be receiving a questionnaire, and that they should be expecting it in about one week. It was hoped that this would help to increase the response rate by familiarizing each recipient with the survey, and by distinguishing it from other unsolicited (and presumably unread) mail that these people receive every day. One week later, on May 10, 1997, the actual survey was mailed to 49 states, with Indiana being excluded. Responses, amounting to 49 states (100% response rate) were received through September.

2.2.4 State Survey Results

2.2.4.1 Speed-Monitoring Characteristics

According to the survey 30 (61%) of the 49 states surveyed changed the number of monitoring stations, while the remaining 19 (39%) did not make any changes (see Table 2.1). Of those thirty states, eight (16%) increased the total number of stations monitored, 11 (22.5%) decreased the number of stations monitored, while 11 (22.5%) discontinued a formal speed monitoring program altogether.

Of the 38 states that continued to monitor speeds, 13 (34%) differentiated speeds by vehicle class, while 26 (66%) did not. The significant difference in the number of states that do monitor speed by vehicle class indicates that most states are not interested in distinguishing speed by vehicle class. Table 2.1 shows that 19 (50%) of the 38 states that continue to monitor speeds monitor in one direction of travel, while 19 (50.00%) of the states monitor speeds in both directions.

Prior to the NMSL repeal states were required to monitor speeds for a 24 hour period and report the results on a quarterly basis (Federal Register 1993). As. Table 2.1 shows, 20 (53%) of the states that continue to have a formal speed monitoring program report results on a quarterly basis. Six states (16%) report results on an as needed basis. Four states (10%) report results either annually or daily. Three states (8%) report results semi-annually and one (3%) state reports results monthly.

Thirty-three (87%) states continue to monitor speeds for a 24-hour period. Two states (5%) either monitor speeds for a 48-hour period or on a continuous basis, while only one state (3%) monitors speed for a 72-hour period.

Table 2.1. State Speed Monitoring Characteristics

Number of Stations	Number of Responses	Percentage
Increase	8	16%
Decrease	11	22.5%
No Change	19	39%
Discontinued	11	22.5%
Vehicle Classification		**Percentage**
Yes	13	34%
No	25	66%
Monitoring Direction		**Percentage**
One Direction	19	50%
Both Directions	19	50%
Sessions per Year		**Percentage**
Daily	4	10%
Monthly	1	3%
Quarterly	20	53%
Semi-Annually	3	8%
Annually	4	10%
As Needed	6	16%
Session Duration		**Percentage**
24 Hours	33	87%
48 Hours	2	5%
72 Hours	1	3%
Continuous	2	5%

2.2.4.2 Site Distribution Determinants

On the speed monitoring survey, respondents were asked to indicate how they distribute speed monitoring stations. The responses are given in Figure 2.1. It should be noted that respondents were asked to check one or more of the specified options. The most common response was random selection by highway class. The second most

common response was distributing stations based on available speed, Weigh in Motion (WIM), and Automated Traffic Recording (ATR) stations. Uniform distribution by highway class and simple random selection were next followed by random selection based on volume. The least common distribution determinant was based on speed limits and crash rates.

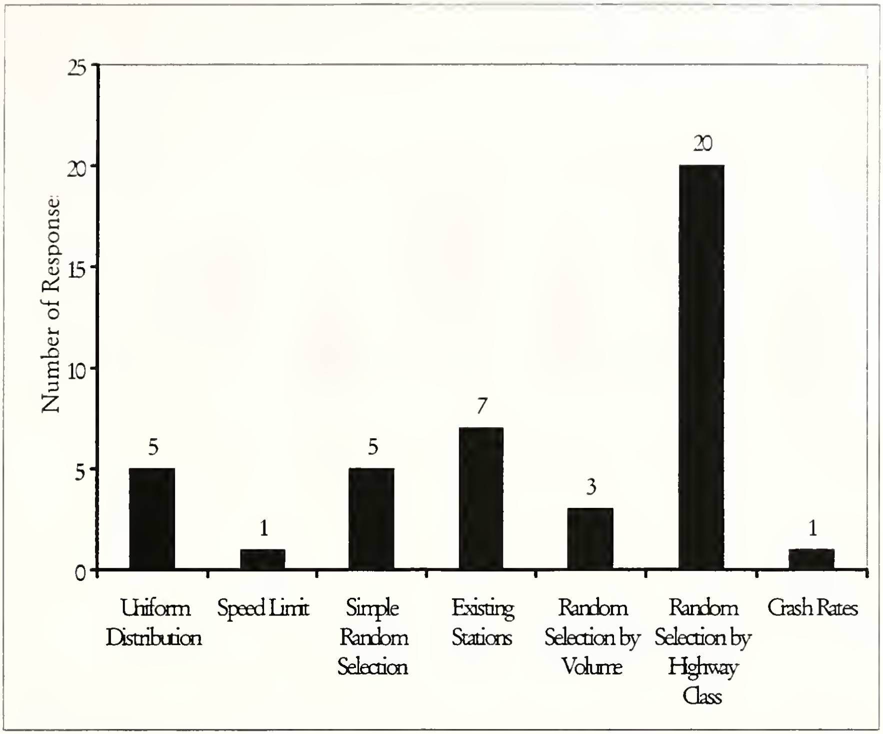
2.2.4.3 Distribution by Highway Class

A question was asked about how many speed monitoring stations a particular state had in each of six highway classes, Rural Interstates, Urban Interstates, Rural US Roads, Urban US Roads, Rural State Roads, and Urban State Roads. Confidence intervals were computed in an effort to estimate the mean percentage of sites in each highway class with 95% certainty (Miller et al. 1990).

Figure 2.2 shows the percentage of sites within each highway class prior to the repeal of the NMSL. From this figure we can see that Rural Interstates had an upper bound of 21.5%, Urban Interstates 13.9%, Rural U.S. 30.5%, Urban U.S. 20.0%, Rural State 28.7%, and Urban State 15.2%.

Figure 2.3 shows the percentage of sites within each highway class following the repeal of the NMSL. The upper bound for Rural Interstates was 26.4%, for Urban Interstates 14.9%, for Rural U.S. 13.4%, for Urban U.S. 23.9%, for Rural State 27.5%, and for Urban State 3.4%.

A comparison of Figure 2.2 and Figure 2.3 would indicate that the percentage of sites within Urban Interstates and Rural State Roads remained relatively constant following the NMSL repeal with a 1.0% increase and 1.2% decrease respectively. Rural Interstates and Urban U.S. Roads experienced slight increases of 4.90% and 3.9% respectively. The most dramatic change in the percentages occurred in Rural U.S. Roads



and Urban State Roads. Following the repeal, Rural U.S. Roads decreased 17.1%, from 30.5% to 13.4%. Urban State Roads decreased 11.8%, from 15.2% to 3.4%.

Figure 2.1. Site Distribution Determinants Following NMSL Repeal

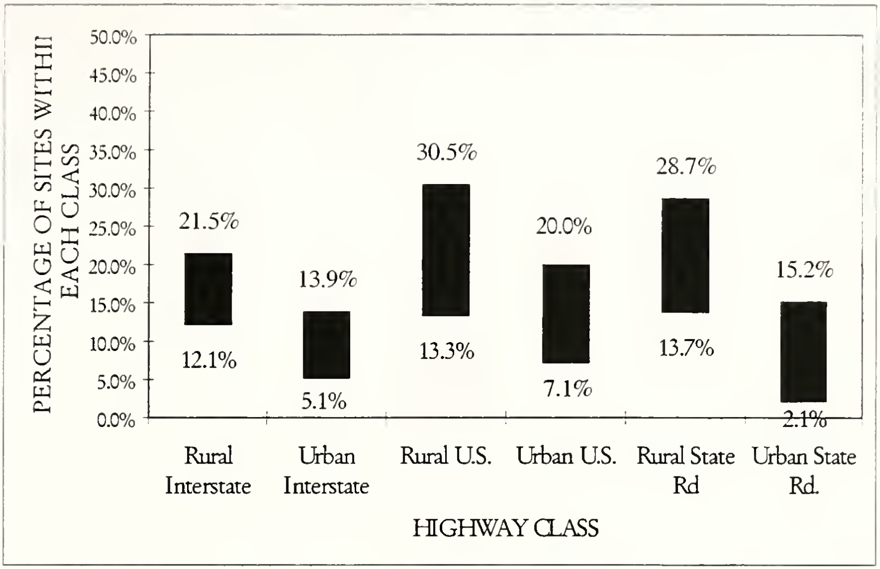


Figure 2.2. 95% Confidence Intervals for Percentage of Speed Monitoring Stations in Each Highway Class (Pre-NMSL)

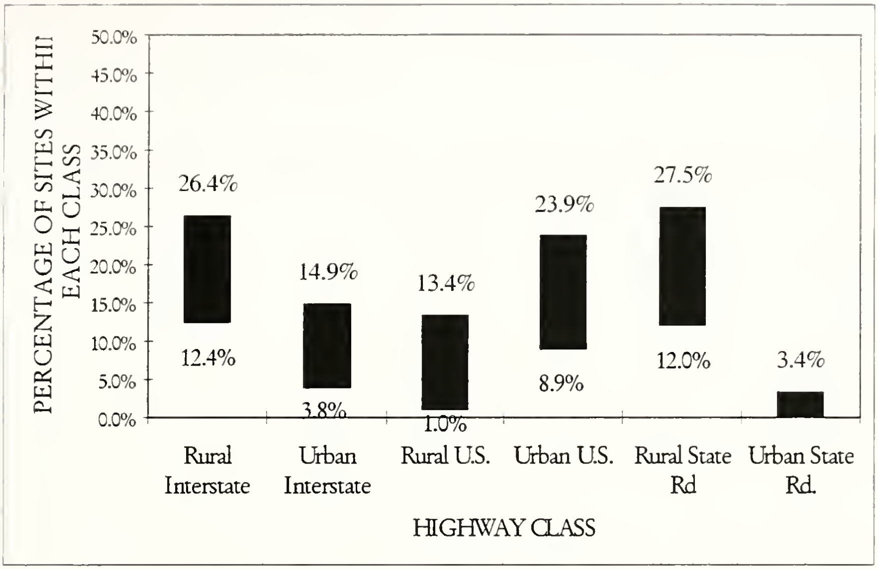


Figure 2.3. 95% Confidence Intervals for Percentage of Speed Monitoring Stations in Each Highway Class (Post-NMSL).

CHAPTER 3 IDENTIFICATION OF SPEED MONITORING NEEDS IN INDIANA

3.1 Preliminary Investigation

The study advisory committee (SAC) for the present project was comprised of research personnel from Purdue University, highway safety engineers from FHWA, enforcement officials from Indiana State Police, and engineers and planners from INDOT's Planning Division, Research Division, and Roadway Management Division. Each of these representatives had an interest in speed monitoring data. The committee considered it important to continue speed monitoring following the repeal of the NMSL in order to devise suitable enforcement measures, to ensure safety on the state road network, to provide speed information to various public and private agencies, and to have reliable data readily available for design, operational, and research needs. After considering the information from other states and possible speed monitoring data needs in their respective agencies, the study committee members provided directions for a survey to be administered in Indiana: the purpose of the survey was to determine if speed monitoring should be continued in Indiana and if so, what should be the characteristics of the monitoring plan.

3.2 Survey Procedure

3.2.1 Survey Development

A simple questionnaire survey was developed and distributed among relevant agencies and organizations in Indiana. Since the purpose of speed monitoring was no longer to certify the compliance with the NMSL, it was necessary to be sure that agencies and organizations still wanted and would use speed monitoring data. Thus, the first portion of the questionnaire addressed these specific questions. Participants were asked if they felt there was a need for a formal speed monitoring program in Indiana.

The second portion of the questionnaire addressed the issue of how to distribute monitoring sites among highway classes. After discussions with the study advisory committee it was decided to consider three factors for site allocation, spatial distribution, relative DVMT distribution, and relative crash distribution. The crash distribution criterion was further broken down into four types of crashes: all crashes, all fatal crashes, speed related crashes, and fatal speed related crashes. The six highway classes chosen were Rural Interstates, Urban Interstates, Rural US Roads, Urban US Roads, Rural State Roads, and Urban State Roads. Sites have historically been distributed by functional highway class. In the proposed plan a different highway classification scheme was considered for two reasons. First, all supporting data used in the present study, such as vehicle miles traveled and crash data, were available for the new classification scheme. This consistency would allow any agency that uses speed data to investigate causal relationships without difficulty. Second, there was evidence to show that a statistically significant difference existed in the mean speed of these highway classes.

In an effort to ensure that the allocation of speed monitoring stations is consistent with the requirements of those who would use the data from speed monitoring, a

procedure had to be undertaken to rank and rate the site distribution criteria that would reflect the group consensus.

For this purpose a Delphi study was used. The Delphi is a technique used to attain opinions with the object of obtaining a consensus from a group of experts. In the present study, the object was to rank and rate speed monitoring station distribution criteria. The Delphi replaces direct confrontation and debate by a carefully planned orderly program of sequential discussions, carried out through an iterative survey (Dalkey et al. 1969). The payoff of a Delphi study is typically a presentation of observed expert concurrence in a given application area where none existed previously (Sackman 1974).

In this portion of the survey participants were first asked to allocate 100 points among the three distribution criteria. The higher the number, the more important that criterion was deemed to be. The next step was to allocate 100 points among the four crash categories. Again, the higher the number, the more important that crash type was deemed to be.

3.2.2 Survey Administration

Survey participants were chosen from a variety of agencies in Indiana including JTRP, INDOT, FHWA, Indiana State Police, and the Department of Revenue. JTRP was chosen because it uses speed data for research needs. INDOT uses data for traffic operations and in the planning and design of transportation systems. FHWA is interested in general speed trends. The Indiana State Police uses data for enforcement. Finally, the Department of Revenue was chosen because it uses the data to calculate fuel taxes and compute revenue estimates.

For each participating organization, a contact person, who would most likely use speed data, was identified and asked to participate in the survey. That person was also

asked to identify other people within that organization likely to participate in the survey.

Having identified the target agencies and survey participants, the next step was to distribute the survey. As a general rule of thumb a large sample consists of thirty or more observations. In this case thirty-one participants were chosen from the above agencies.

Before the questionnaire was mailed, a courtesy call was placed to the thirty-one people who would be participating in the survey. This was to let each participant know that they would be receiving a questionnaire, and that they should be expecting it in about one week. Furthermore, because anonymity improves the quality of the Delphi Process (Dalkey 1970), survey participants were told they would have complete anonymity. The survey questionnaire included a cover letter explaining the purpose of the survey and associated research.

The Delphi Process is iterative, therefore survey participants were asked to complete a number of rounds. First, the survey participant completed the two-part survey and returned it to the facilitator. The facilitator then analyzed the individual comments and produced a report documenting the response of the group. The participants were then given the chance to compare what they said in the second part of the survey dealing with site distribution criteria to the group's normative response and indicate a new response, if so desired. In the present study, consistent results were obtained after two rounds, indicating a high level of consensus.

3.2.3 Survey Results

3.2.3.1 General Speed Monitoring

Table 3.1 shows that all but one (96.77%) of those surveyed felt a formal speed monitoring program should continue. The one person, who did not think a formal speed monitoring program was necessary, commented: "Indiana has not demonstrated a need for network wise speed data, temporary monitoring on an-as needed basis would suffice." A response which typically represented how most respondents felt about the continuation of a formal speed monitoring program was: "INDOT needs a continuing speed monitoring program, it gives good, essential, valuable data and information for making prudent traffic engineering decisions."

Table 3.1 also shows that 29 (93.55%) of the 31 respondents indicated that they used speed monitoring data. Some of the most common responses for data uses were: informational purposes, verification of design speed, transportation modeling, policy analysis, correlation with crash data, traffic flow relationships, and public information requests.

3.2.3.2 Site Distribution

Table 3.2 provides the results of the Delphi Process. Following the first round, DVMT was the highest rated distribution criterion with an allocation of 36 points. Crash distribution was second with 33 points and spatial distribution was third with an allocation of 31 points.

The crash results showed speed crashes to be the most important crash distribution criterion with an average 29.3 points. This was followed by fatal speed crashes with an average of 28.6 points. All crashes were third with an average of 24.7 points and all fatal crashes fourth with an average of 20.0 points.

In the second round, the order of importance for both the distribution criteria and crash types changed. As Table 3.2 shows, DVMT continued to be the most important distribution criterion with an average 34.8 points. This was closely followed by spatial distribution, which moved up from third place in the first place with an average value of 34.2. Crash distribution was last with a mean value of 31.0.

The order of importance for crash types also changed. Speed related crashes remained in first with an average 28.8 points. All crashes moved up from third to second with an average 27.9. Fatal speed crashes dropped from second to third place with an average of 24.3. Finally, all fatal crashes remain fourth with an average of 19.0. Because the Delphi process deliberately manipulates responses toward minimum dispersion of opinion in the name of consensus (Sackman 1974), there is no advantage in continuing beyond two rounds (Martino 1972). Therefore, the present survey stopped after two rounds.

Table 3.1. Continuation and Use of Speed Monitoring

Continue Monitoring	Number of Responses	Percentage
Yes	30	97%
No	1	3%
Use Data	**Number of Responses**	**Percentage**

Yes	29	94%
No	2	6%

Table 3.2. Delphi Process Results

Distribution Criteria	Round 1 Mean	Round 1 Standard Deviation	Round 1 Rank	Round 2 Mean	Round 2 Standard Deviation	Round 2 Rank
Spatial	31.0	13.8	3	34.2	11.3	2
Crash	33.0	10.9	2	31.0	9.4	3
DVMT	36.0	9.4	1	34.8	6.7	1
Crash Type						
All	24.7	18.3	3	27.9	16.9	2
All Fatal	20.0	9.6	4	19.0	8.2	4
Speed	29.3	9.8	1	28.8	7.4	1
Fatal Speed	28.6	8.9	2	24.3	10.3	3

3.2.4 Conclusions

The first part of this survey indicated an overwhelming majority of the survey participants believed a formal monitoring program should continue. Furthermore, a great majority of the survey participants indicated the use of speed monitoring data.

The second part of the survey established DVMT as the most important distribution criterion followed by spatial and crash distribution. For the crash distributions, the criterion of speed related crashes was found to be most important followed by those related to all crashes, fatal speed crashes, and all fatal crashes. Chapter 4 of this report will develop a speed monitoring program that uses the results of this survey to determine the number and locations of the speed monitoring sites.

CHAPTER 4 PROPOSED MONITORING PLAN

4.1 Introduction

This chapter presents a sampling plan, which has been designed to monitor the speeds of all vehicles traveling on paved roads with a 55-mph or greater speed limit. The presentation of this chapter is divided into the following sections:

- Overview of the proposed monitoring program;
- Number of monitoring sessions per year;
- Duration of monitoring period for individual sampling sessions;
- Minimum number of statewide sampling locations;
- Speed by vehicle class;
- Speed by direction of travel;
- Allocation of sampling locations by highway class; and
- Selection of highway sample segments.

4.2 Overview of the Proposed Monitoring Program

To be compatible with the data collected under the FHWA program during the past decades, an effort was made to design the proposed program to be as consistent as possible with the existing program. Consequently, it was decided to follow in the proposed program the statistical requirement of a 2.0 mph maximum error of estimate at a 5 percent significance level as used in the Federal program (U.S. DOT 1975). This

requirement was used to determine the following core components of the proposed program: the number of monitoring sessions per year, duration of monitoring period for individual sampling sessions, and the minimum number of statewide sampling locations. In addition, the proposed program will include an evaluation of monitoring of speed by vehicle length and by direction of travel, in order to accommodate the perceived needs of Indiana agencies. Also, the proposed program will have speed monitoring stations allocated by highway class based on the distribution criteria established in Chapter 3. Finally, a procedure will be discussed to determine locations of monitoring sites utilizing existing speed monitoring, weigh-in-motion (WIM), and automated traffic recording (ATR) stations.

4.3 Number of Monitoring Sessions Required Per Year

4.3.1 Background

The current speed monitoring program collects speed data every quarter of the year, as required by the FHWA (U.S. DOT 1975). However, the need for monitoring speed every quarter can be questioned. While it is well documented that traffic volume varies by time of year (ITE 1976), the variation in mean speed by time of year may not be significant. In the present study an investigation was made to examine if monitoring speed every quarter was necessary. This analysis was conducted by first seeing if a significant difference in mean speed existed by quarters and then seeing if there was a significant difference between each quarterly speed distribution.

4.3.2 Statistical Methodology

A three-stage nested factorial design (Montgomery 1997) was used to analyze the total number of monitoring sessions required per year. In this model, "district" is nested under "year", and "highway class" is nested under "district". A nested factorial design was chosen because levels of one factor are similar but not identical for different levels of another factor. This means, for example, that highway class 1 in district 1 of year 1 is similar to, but not identical to, highway class 1 in district 1 of year 2. Therefore, highway class is nested under district 1 in year 1. Data for this analysis were taken from 1983-1997 historical speed monitoring data collected in Indiana. The database involved 15 years, 4 quarters each, 6 districts, and 6 highway classes. The total number of stations was 320 representing different monitoring locations used over the 15-year period.

The speed model for the three-stage nested factorial design used in this experiment representing the main effects and their associated interactions is given by:

$$\begin{aligned} Yijklm = {} & \mu + \alpha_i + \beta j + \chi_k + \alpha\beta_{ij} + + \alpha\chi_{ik} + \beta\chi_{jk} + \alpha\beta\chi_{ijk} + \delta_{(ijk)l} \\ & + \gamma_m + \alpha\gamma_{im} + \beta\gamma_{jm} + \alpha\beta\gamma_{ijm} + \alpha\chi\gamma_{ikm} + \beta\chi\gamma_{jkm} + \alpha\beta\chi\gamma_{jkm} \\ & + \delta\gamma_{(ijk)lm} + \varepsilon_{ijklm} \end{aligned} \tag{1}$$

where

Yijklm is the estimated average speed for i^{th} year, in j^{th} district, for k^{th} highway class, at l^{th} station , and within the m^{th} quarter,

μ is the overall sample mean, α_i is the effect of the i^{th} year,

β_j is the effect of the j^{th} district, χ_k is the effect of the k^{th} highway class,

$\alpha\beta_{ij}$ is the interaction between the i^{th} year and j^{th} district,

$\alpha\chi_{ik}$ is the interaction between the i^{th} year and k^{th} highway lass,

$\beta\chi_{jk}$ is the interaction between the j^{th} district and k^{th} highway class,

$\alpha\beta\chi_{ijk}$ is the interaction between the i^{th} year j^{th} district and k^{th} highway class,

$\delta_{(ijk)l}$ is the effect of the l^{th} station within the k^{th} highway class within the j^{th} district within the i^{th} year, γ_m is the effect of the m^{th} quarter,

$\alpha\gamma_{im}$ is the effect of the interaction between the i^{th} year and m^{th} quarter,

$\beta\gamma_{jm}$ is the effect of the interaction between the j^{th} district and m^{th} quarter,

$\chi\gamma_{km}$ is the effect of the interaction between the k^{th} highway class and m^{th} quarter,

$\alpha\beta\gamma_{ijm}$ is the effect of the interaction between the i^{th} year the k^{th} highway class and the m^{th} quarter,

$\alpha\chi\gamma_{ikm}$ is the effect of the interaction between the i^{th} year the k^{th} highway class and the m^{th} quarter,

$\beta\chi\gamma_{jkm}$ is the effect of the interaction between the j^{th} district the k^{th} highway class and the m^{th} quarter,

$\alpha\beta\chi\gamma_{ijkm}$ is the effect of the interaction between the i^{th} year the j^{th} district the k^{th} highway class and the m^{th} quarter,

$\delta\gamma_{(ijk)lm}$ is the effect of the interaction between the l^{th} station within the k^{th} highway class within the j^{th} district within the i^{th} year and the m^{th} quarter, and

ε_{ijklm} is the error term.

The model was entered into Statistical Analysis Software (SAS) (SAS Institute Inc. 1988) in order to test for significant main and interaction effects. The Student-Newman-Keuls (SNK) multiple range test was used on all main effect means (Montgomery 1997). The SNK method compares all pairs of treatment means in an effort to discern which means differ from each other.

4.3.3 Results

The items of interest in this analysis were variation of average speeds by quarter, variation by quarter by class, variation by quarter by district, and variation by quarter

by district by class. Table 4.1 shows the significance probabilities associated with each main effect and interaction used in this analysis. From this table the significance of the relevant main effects and their interactions can be determined, as discussed below.

The probability associated with the main effect of quarter, denoted by γ_m, of 0.9054 indicates that no significant difference in mean speed existed between quarters. This can be further seen in the presentation of mean speeds stratified by quarter, shown in Table 4.2. From this table it can be seen than the mean speed only varied from 58.8 mph in quarter 1 to 58.9 mph in quarter 4, and the mean speed was not significantly different by quarter.

The probability associated with the quarter by class interaction effect, denoted by $\chi\gamma_{km}$, of 0.8790 indicates that mean speed is not significantly different by quarter and highway class. The probability associated with the quarter by district interaction effect, denoted by $\beta\gamma_{jm}$, of 0.5505 indicates that mean speed is not significantly different by quarter and district. The probability associated with the quarter by district by class interaction effect, denoted by $\alpha\beta\chi\gamma_{ijkm}$, of 0.6947 indicates that mean speed is not significantly different by quarter within each highway class and district.

In order to determine if the speed distributions were different by highway class and quarter, speed data from a randomly selected station in each highway class for 1996 were analyzed. The quarterly distributions were plotted for each highway class and are shown in Figure 4.1 through Figure 4.6. Chi-squared tests were used to compare the quarterly distributions for each highway class (Fienberg 1980). Table 4.3 shows the results of this analysis. From this table it can be seen that the distributions were significantly different from each other.

Although the mean speed was found to be not significantly different by quarter, the speed distributions, however, were significantly different. Consequently, it may be desirable to continue to monitor speed every quarter.

Table 4.1. Probability Table for the Three-Stage Nested Factorial, Mixed Effects Model

Source	Effect	Pr > F
α_i	YEAR	0.0001
β_j	DIST	0.0001
χ_k	CLASS	0.0001
$\alpha\beta_{ij}$	YEAR*DIST	0.9986
$\alpha\chi_{ik}$	YEAR*CLASS	0.9911
$\beta\chi_{jk}$	DIST*CLASS	0.0001
$\alpha\beta\chi_{ijk}$	YEAR*DIST*CLASS	0.9636
$\delta_{(ijk)l}$	STA(YEAR DIST CLASS)	--
γ_m	QRT	0.9054
$\alpha\gamma_{im}$	YEAR*QRT	0.5219
$\beta\gamma_{jm}$	QRT*DIST	0.5505
$\chi\gamma_{km}$	QRT*CLASS	0.8790
$\alpha\beta\gamma_{ijm}$	YEAR*QRT*DIST	0.0024
$\alpha\chi\gamma_{ikm}$	YEAR*QRT*CLASS	0.0001
$\beta\chi\gamma_{jkm}$	QRT*DIST*CLASS	0.6947
$\alpha\beta\chi\gamma_{ijkm}$	YEAR*DIST*CLASS*QRT	0.001778
$\delta\gamma(ijk)_{lm}$	STA(YEAR DIST CLASS)*QRT	--

Table 4.2. Student-Newman-Keuls Test for Quarter

SNK Grouping	Mean	Quarter
A	58.9	4
A		
A	58.9	3
A		
A	58.8	2
A		
A	58.8	1

** Means with the same SNK groupings are not significantly different

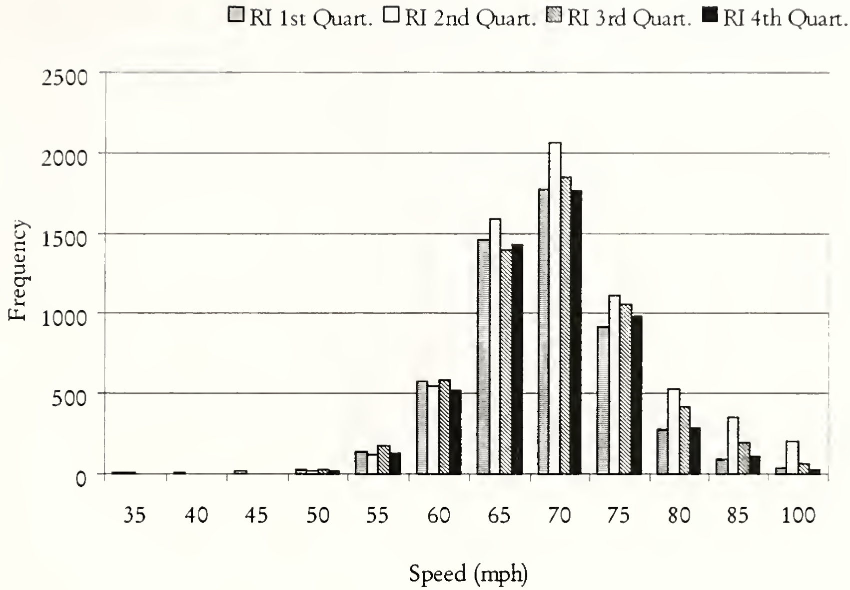


Figure 4.1. Quarterly Histogram for Rural Interstates

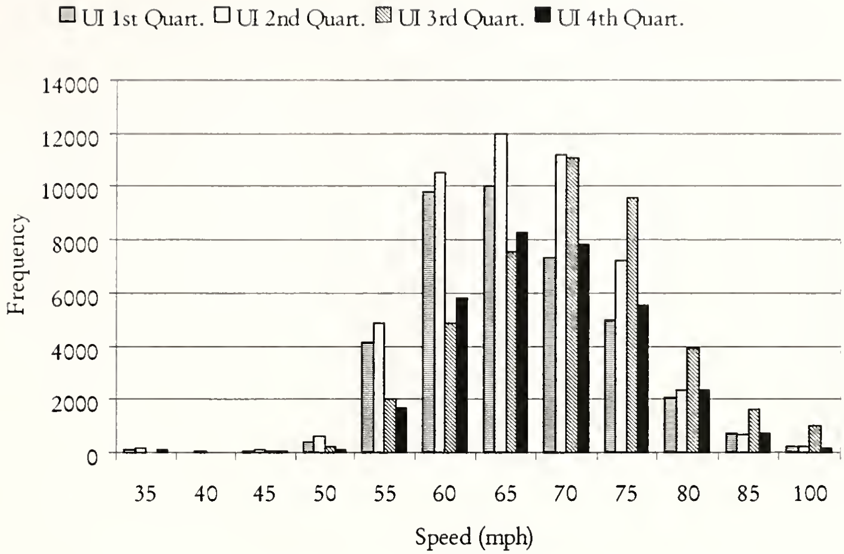


Figure 4.2. Quarterly Histogram for Urban Interstates

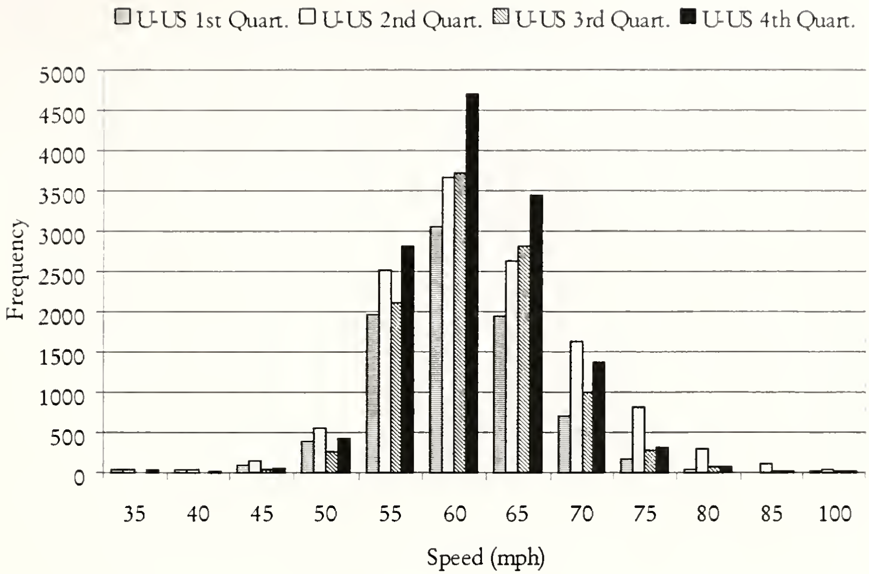


Figure 4.3. Quarterly Histogram for Rural U.S. Road

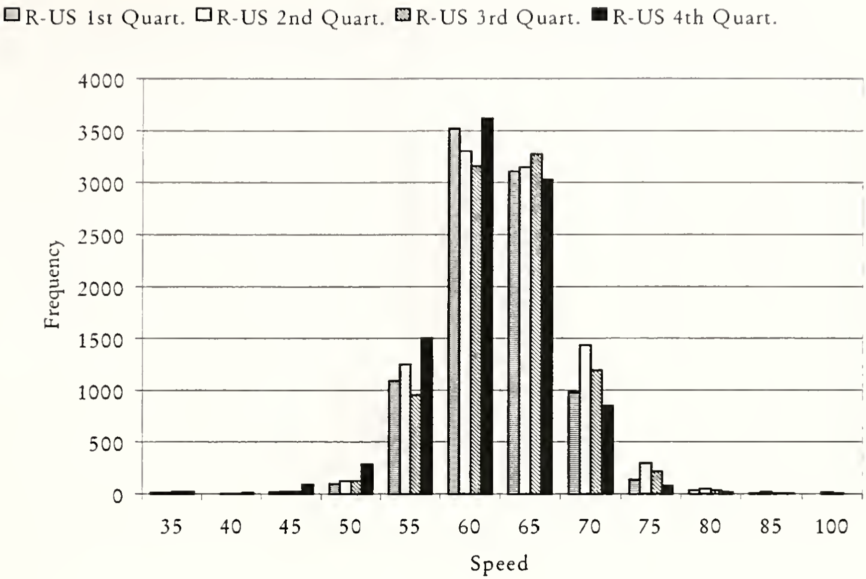


Figure 4.4. Quarterly Histogram for Rural US Roads

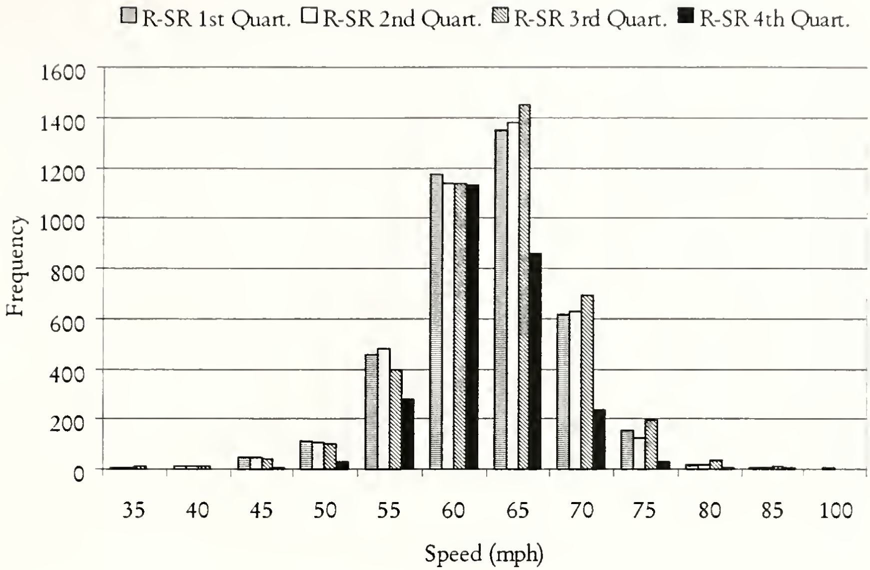


Figure 4.5. Quarterly Histogram for Rural State Roads

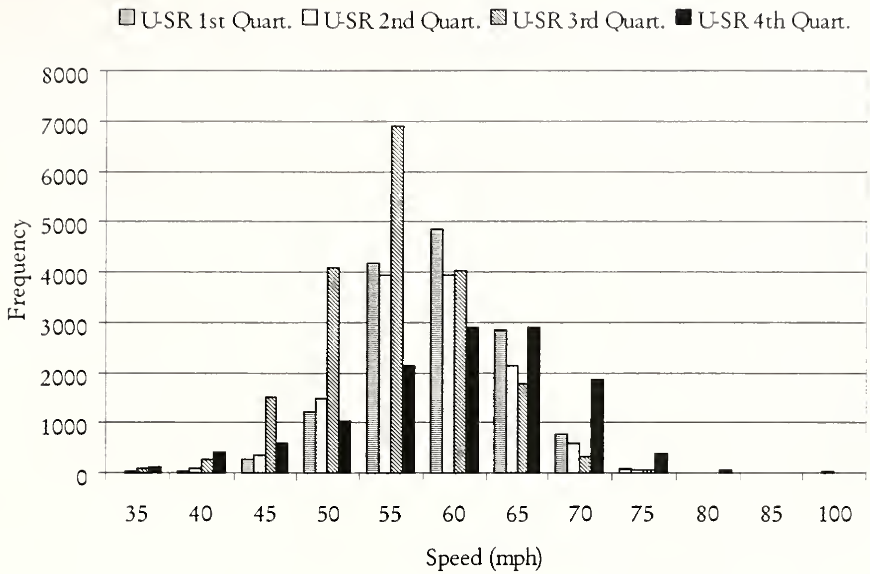


Figure 4.6. Quarterly Histogram for Urban State Roads

Table 4.3. Chi-Squared Comparison of Quarterly Speed Distributions

Rural Interstates

Quarter		Quarter	Test Stat.	P-Value
1	Vs.	2	1,228	1.88E-256
1	Vs.	3	196	4.62E-36
1	Vs.	4	39	4.75E-05
2	Vs.	3	219	8.67E-41
2	Vs.	4	326	2.85E-63
3	Vs.	4	100	1.83E-16

Urban Interstates

Quarter		Quarter	Test Stat.	P-Value
1	Vs.	2	1212.507	3.26E-253
1	Vs.	3	14710.64	0.00E+00
1	Vs.	4	3074.451	0.00E+00
2	Vs.	3	13194.31	0.00E+00
2	Vs.	4	2061.965	0.00E+00
3	Vs.	4	4296.53	0.00E+00

Urban US Roads

Quarter		Quarter	Test Stat.	P-Value
1	Vs.	2	5186.432	0.00E+00
1	Vs.	3	436.6968	9.75E-87
1	Vs.	4	318.307	1.21E-61
2	Vs.	3	1075.988	8.42E-224
2	Vs.	4	1173.978	6.57E-245
3	Vs.	4	149.7349	1.69E-26

Rural US Roads

Quarter		Quarter	Test Stat.	P-Value
1	Vs.	2	496.6323	1.68E-99
1	Vs.	3	210.7743	4.30E-39
1	Vs.	4	901.4121	3.08E-186
2	Vs.	3	147.2375	5.46E-26
2	Vs.	4	955.1085	8.74E-198
3	Vs.	4	941.5983	7.04E-195

Table 4.3. Chi-Squared Comparison of Quarterly Speed Distributions (Continued)

Rural State Roads

Quarter		Quarter	Test Stat.	P-Value
1	Vs.	2	29.33917	2.01E-03
1	Vs.	3	91.37307	8.97E-15
1	Vs.	4	360.0255	1.83E-70
2	Vs.	3	84.48822	1.99E-13
2	Vs.	4	379.1937	1.59E-74
3	Vs.	4	467.1427	3.23E-93

Urban State Roads

Quarter		Quarter	Test Stat.	P-Value
1	Vs.	2	483.4552	1.08E-96
1	Vs.	3	11539.72	0.00E+00
1	Vs.	4	11607.28	0.00E+00
2	Vs.	3	5385.975	0.00E+00
2	Vs.	4	7838.305	0.00E+00
3	Vs.	4	22134.25	0.00E+00

4.4 Duration of Monitoring Period for Individual Sampling Sessions

4.4.1 Background

Under the FHWA program a 24-hour monitoring period was selected for the following reasons. First, it accounted for the varying traffic conditions affecting speeds within a day. Second, the within-cluster (daily) variation would not allow for a reduction in the number of locations required even if much longer periods were used. The 24- hour monitoring period minimized cost in terms of the combination of sampling locations required and the need for equipment. For the proposed program, the Indiana State Police (ISP) wanted to see if day of week was a significant factor in

determining mean speed. If so, it would be necessary to monitor speeds for a longer period, thus the need for this analysis.

4.4.2 Statistical Methodology

In order to test if "day of week" is a significant factor in determining mean speed, a two-stage nested factorial mixed effects model was developed. The speed model representing the main effects and their associated interactions is given by:

$$Y_{ijk} = \mu + \delta_i + \varphi_{ij} + \lambda_k + \delta_i \lambda_k + + \varphi_{ij\lambda k} + \varepsilon_{ijk} \quad (2)$$

where, Y_{ijk} is the average speed at ith station, in jth direction travel, on kth day,

μ is the overall sample mean,

δ_i is the effect of the ith station,

φ_{ij} is the effect of the j^{th} direction of travel within the i^{th} station,

λ_k is the effect of the k_{th} day,

$\delta_i\lambda_k$ is the effect of the interaction between the i^{th} station and the k^{th} day,

$\varphi_{ij}\lambda_k$ is the interaction effect of the j^{th} direction within the i^{th} station and the k^{th} day,

and ε_{ijk} is a random error component.

Data for this experiment were obtained from 27 WIM stations distributed throughout the state. WIM stations, rather than the normal speed monitoring stations, were used for the analysis because WIM stations have the ability to monitor speeds in both directions, while regular speed monitoring stations currently monitor speeds in only one direction.

4.4.3 Results

The item of interest in this part of the analysis was variation by day of week.

Table 4.4 shows the significance probabilities table for this model. From this table it can be seen that the effect of day on mean speed, denoted by λ_k, is not significant (Pr > F=0.8386). Furthermore,

Table 4.5 shows the mean speed stratified by day of week only varies between 61.96 and 62.21 mph. It can, therefore, be concluded that day of week was not a significant factor in explaining the variation in mean speeds in Indiana, and the future program can continue to monitor speeds for a 24-hour period.

Table 4.4. Probability Table for the Two-Staged Nested Factorial, Mixed Effects Model

Source	Effect	Pr > F
δ_i	STA	0.0001
$\varphi_{(i)j}$	DIR (STA)	0.0001
λ_k	DAY	0.8386

$\delta\lambda_{ik}$	STA * DAY	1.0000
$\varphi\lambda_{(i)jk}$	DIR (STA) * DAY	0.9999

Table 4.5. SNK Results for Speed by Day of Week

SNK Grouping	Mean	Day
A	62.2089	Friday
A		
A	62.1976	Saturday
A		
A	62.1943	Monday
A		
A	62.1127	Thursday
A		
A	62.0791	Sunday
A		
A	62.0048	Wednesday
A		
A	61.9628	Tuesday

** Means with the same SNK grouping are not significantly different

4.5 Speed by Direction

4.5.1 Background

From the survey of speed monitoring practices in other states presented in Chapter 2, it was found that half of the states that continued to monitor speeds do so in both directions of travel. Consequently, INDOT wanted to see if it was necessary for Indiana to measure speed by direction. Also, Indiana State Police felt speed by direction may be important for enforcement purposes.

4.5.2 Statistical Methodology

In order to test if direction of travel is a significant factor in determining mean speed, the two-stage nested factorial mixed effects model, presented in Equation 2, was used.

4.5.3 Results

Of interest in this analysis was whether mean travel speed was different for each direction of travel. The probability table for this model (shown in

Table 4.4 of the previous section) indicates there exists significant evidence to show that mean speeds were different by direction of travel ($Pr > F = 0.001$). Based on this information, speed may be monitored for each travel direction, particularly for divided highways.

4.6 Speed by Vehicle Length

4.6.1 Background

It is well known that trucks are much heavier and have slower acceleration rates and require more time to decelerate than passenger vehicles. Consequently, there is an increased potential of high severity in case of crashes between trucks and smaller vehicles. Higher speeds add to the severity of these crashes. At the same time, speed variance is increased when trucks travel at a different speed than other vehicles (Jernigan 1994, Garber 1991). In Indiana, speed limit for trucks on Rural Interstates is 60 mph while for passenger vehicles it is 65 mph. Representatives from Indiana State Police, INDOT, and the Department of Revenue requested that an analysis be made to determine if a difference existed in mean vehicle speed based on vehicle length, not only on Rural Interstates but also on other Roads.

4.6.2 Statistical Methodology

In order to test if mean speed varies by vehicle length a two-stage nested factorial mixed effects model was developed. The statistical model has station nested under highway class. Station is nested under highway class because different levels of station are similar, but not identical for different levels of highway class.

The two-stage nested factorial, mixed effects model used in this experiment, representing the main effects and their associated interactions, is given by:

$$Y_{ij} = \mu + \chi_i + \delta_{ij} + \kappa_k + \chi_i\kappa_k + \delta_i\kappa_{jk} + \varepsilon_{ijk} \tag{3}$$

where, Y_{ij} is the average speed

μ is the overall sample mean,

χ_i is the effect of the ith vehicle class,

δ_{ij} is the effect of the jth station within the ith highway class,

κ_k is the effect of the kth vehicle length,

$\chi_i\kappa_k$ is the effect of the interaction between the ith highway class and the kth vehicle length,

$\delta_i\kappa_{jk}$ is the interaction effect of the jth station within the ith highway class and the kth vehicle length, and

ε_{ijk} is the error term.

As the existing program, based on the Federal requirements, has not monitored speed by vehicle class, a special data collection effort was made during the four quarters of 1997 to record speed data separately for trucks at randomly selected existing monitoring stations. Three vehicle classes were considered. Class 1 consisted of passenger cars with 20 feet or less length, Class 2 for medium sized trucks between 21 and 40 feet in length, and Class 3 for large trucks 40 feet and greater in length.

4.6.3 Results

Of interest in this experiment was whether vehicle class and the interaction between highway class and vehicle class was significant. Table 4.6 shows the results of the experiment. From this table it can be seen that highway class, vehicle length, and the interaction between highway class and vehicle length were all significant with probability ($Pr > F$) values of 0.0001. Because Indiana currently employs differential speed limits on Rural Interstates, it could be expected that the interaction between highway class and vehicle class would be significant. Table 4.7 shows the SNK results for speed by vehicle class. From this table it can be seen that the mean speeds for the three vehicle classes considered were significantly different from each other. Passenger

cars had a mean speed of 60.2 mph, single unit trucks and buses had a mean speed of 58.2 mph, and combination trucks had a mean speed of 59.4 mph. The results are somewhat unexpected because one would think single unit trucks travel at a higher speed than combination trucks.

Table 4.6. Probability Table for Two-Stage Nested Factorial, Mixed Effects Model for Speed by Vehicle Class.

Source	Effect	Pr > F
χ_i	HCLSS	0.0001
$\delta_{(i)j}$	STA (HCLSS)	-
κ_k	CLASS	0.0001
$\chi\kappa_{ik}$	HCLSS * CLASS	0.0001
$\delta\kappa_{(i)jk}$	STA (HCLSS) * CLASS	-

Table 4.7. SNK Results for Speed by Vehicle Length

SNK Grouping	Mean	Class
A	60.2294	1
B	59.3546	3
C	58.2071	2

** Means with the same SNK grouping are not significantly different

4.7 Number of Statewide Monitoring Stations

Two concepts were used in determining the number of statewide monitoring stations, reliability of statistical estimates and coverage of population sampled (U.S. DOT 1975). In the FHWA program, the standard statistical requirements for determining sample size are dependent upon the statewide standard deviation of the

percentage of vehicles exceeding the posted speed limit rather than on mileage or vehicle miles of travel. Since this figure would be similar in most states, the resultant sample sizes were nearly the same, with the exceptions of very small states. This meant that statistically the sizes of the speed populations of different states had very little influence on the sample sizes required for estimation. Having nearly equal samples for the different states did not provide data that were representative of the widely varying travel characteristics found among the states. The concept of "coverage of population sampled" was then provided to balance the work load among the states, and to provide a margin of increased accuracy for the larger states with larger mileages and DVMT.

The FHWA program determined the minimum sample size needed for a state under each of the two concepts and then selected the larger of the two numbers as the statewide minimum sample size. In this manner the reliability requirement would always be met and the sample size would be sensitive to the varying amounts of travel in the states (U.S. DOT 1975). The present study adopted the FHWA approach in determining the total number of stations in the proposed program.

4.7.1 Reliability Requirement

To determine the number of locations required to obtain the desired precision, a preliminary estimate of the standard deviation was estimated. The default value for this parameter, set by the FHWA of 7.0% was used by the present study to determine the number of stations required. The formula to calculate the number of monitoring stations is given by:

$$n_o = \left[\frac{z_{.95} * S(P_{st})}{d} \right]^2 \tag{4}$$

where,

n_o = sample size,

$z_{.95}$ = value of the normal distribution based on a one-sided 95 percent confidence interval,

S(Pst) = standard deviation of the percentage of vehicles exceeding the posted speed limit,

d = precision level required (2.0 mph).

For Indiana, the number of sampling segments required by the reliability of statistical estimates criterion was 38.

4.7.2 Coverage of Population

The coverage concept was designed to allocate locations based on the amount of travel (DVMT) subject to the posted speed limit in the state. This concept was needed to provide a balanced sample size; to compensate for the additional variation which may be present due to larger volume or larger mileage; and for the potential variation in speed enforcement activities of different police departments, districts, or jurisdictions within a state.

Using DVMT data from the 1997 HPMS database the number of monitoring stations required for Indiana under the coverage concept would be 26. Therefore, taking the greater of the reliability criterion and the coverage criterion, 38 stations would be required in the proposed program.

4.8 Site Distribution

4.8.1 Introduction

Having determined the statewide number of speed monitoring stations necessary, the next step was to distribute them by highway class. As mentioned in Chapter 3, the three distribution criteria adopted in the present study were spatial distribution, DVMT distribution, and crash distribution. The crash distribution criterion was further broken

into four crash types, all crashes, all fatal crashes, speed related crashes, and fatal speed related crashes. The expected site distributions were first computed for each criterion and crash type. The individual distributions were then combined into a composite distribution based on the individual criterion's importance. The importance values were ascertained from a Delphi study presented in Chapter 3.

4.8.2 Criteria to Distribute Monitoring Stations

The procedure to distribute the speed monitoring sites will be described for each of the three criteria in the next sections.

4.8.2.1 Spatial Distribution:

The procedure used to distribute the speed monitoring stations by highway class according to the spatial criterion considered six districts of INDOT as separate geographical areas, as shown in Figure 4.7. The HPMS database was used to calculate the number of lane-miles in each highway class for each district, giving the percentage of lane miles by highway class by district. This percentage was then multiplied by the total number of stations, giving the number of stations by highway class by district. These calculations are shown in Table 4.8. The number of sites in each highway class was then summed over the district, giving the expected number of stations in each highway class for the state, as shown in Table 4.9.

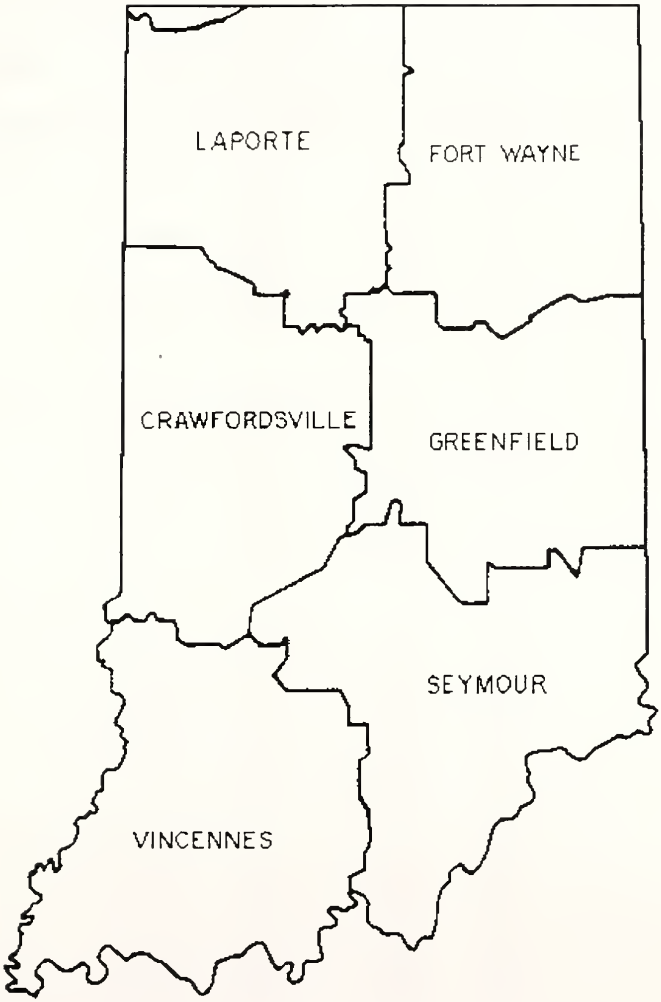


Figure 4.7. INDOT Districts

Table 4.8. Estimation of Number of Stations Under Spatial Distribution

District	Highway Class		Lane-Miles Percentage	Lane-Miles Total Number	Number of Stations
Laporte	Interstates	Rural	6.33%	549	2
		Urban	4.39%	380	2
	U.S. Roads	Rural	4.54%	394	1
		Urban	1.36%	118	1
	State Roads	Rural	2.85%	247	1
		Urban	0.38%	33	0
Fort Wayne	Interstates	Rural	8.26%	716	3
		Urban	1.28%	111	1
	U.S. Roads	Rural	5.32%	461	2
		Urban	0.49%	43	0
	State Roads	Rural	2.31%	200	1
		Urban	0.18%	16	
Crawfordsville	Interstates	Rural	8.30%	720	3
		Urban	1.14%	99	0
	U.S. Roads	Rural	1.64%	142	1
		Urban	0.43%	37	
	State Roads	Rural	3.42%	296	1
		Urban	0.32%	28	0
Greenfield	Interstates	Rural	4.81%	417	2
		Urban	8.47%	734	3
	U.S. Roads	Rural	2.11%	183	1
		Urban	0.41%	35	
	State Roads	Rural	2.57%	223	1
		Urban	0.70%	61	0

Table 4.8. Estimation of Number of Stations Under Spatial Distribution (Continued)

District	Highway Class		Lane-Miles Percentage	Lane-Miles Total Number	Number of Stations
Vincennes	Interstates	Rural	4.93%	427	2
		Urban	0.53%	46	0
	U.S. Roads	Rural	4.05%	351	2
		Urban	0.28%	25	
	State Roads	Rural	2.64%	229	1
		Urban	0.37%	32	1
Seymour	Interstates	Rural	7.11%	616	3
		Urban	1.60%	138	1
	U.S. Roads	Rural	2.14%	186	1
		Urban	0.23%	20	0
	State Roads	Rural	3.79%	328	1
		Urban	0.31%	27	0
			100.00%	8,665	38

Table 4.9. Statewide Site Distribution by Lane-Miles

Highway Class		Lane-Miles Percentage	Lane-Miles Total Number	Number of Stations
Interstates	Rural	39.75%	3,444	15
	Urban	17.41%	1,508	7
U.S. Roads	Rural	19.81%	1,716	8
	Urban	3.19%	277	1
State Roads	Rural	17.58%	1,523	6
	Urban	2.26%	196	1
		100.00%	8,665	38

4.8.2.2 DVMT Distribution:

To determine site distribution based on the DVMT criterion the HPMS database was used to compute DVMT for each highway class. The DVMT for each highway class was then divided by the total DVMT subject to the 55-mph or greater speed limit, giving the percentage of DVMT for each highway class. That percentage was next multiplied by the total number of stations, giving the expected number of stations by highway class for the DVMT criterion. These calculations are shown in Table 4.10.

Table 4.10. Statewide Site Distribution by DVMT

Highway Class		DVMT Percentage	DVMT Total Number	Number of Stations
Interstates	Rural	40.74%	20,469,678	15
	Urban	38.41%	19,298,759	15
U.S. Roads	Rural	10.59%	5,320,672	4
	Urban	2.57%	1,291,299	1
State Roads	Rural	5.78%	2,906,413	2
	Urban	1.90%	956,518	1
		100.00%	50,243,340	38

4.8.2.3 Crash Distribution:

To allocate stations according to the crash criterion an average crash distribution was computed for each of the four crash types. The 1991-95 crash data from the Indiana State Police Crash Information System Crash Master Files was used. This database contained records on all reported crashes in Indiana. Table 4.11 through Table 4.14 show the average crash distributions for each of the four crash types.

Once the average crash distribution for each crash type and for each highway class was computed, the percentage value was multiplied by the total number of stations, giving the expected number of stations by highway class for each crash criterion. This procedure was repeated for each of the four crash types, and is shown in Table 4.15 through Table 4.18.

Table 4.11. Average Distribution of All Crashes

Highway Class		1991	1992	1993	1994	1995	Average
		Percentage					
Interstates	Rural	12.53%	11.70%	11.65%	12.04%	11.90%	11.97%
	Urban	6.06%	5.75%	6.40%	6.21%	6.25%	6.13%
U.S. Roads	Rural	19.46%	19.55%	18.51%	18.99%	17.55%	18.81%
	Urban	13.57%	14.10%	14.30%	14.98%	15.67%	14.52%
State Roads	Rural	34.41%	34.61%	33.73%	32.72%	32.56%	33.61%
	Urban	13.97%	14.29%	15.41%	15.06%	16.07%	14.96%
Total		100%	100%	100%	100%	100%	100%

Table 4.12. Average Distribution of All Fatal Crashes

Highway Class		1991	1992	1993	1994	1995	Average
		Percentage					
Interstates	Rural	12.80%	14.79%	12.80%	12.30%	13.59%	13.26%
	Urban	2.65%	2.76%	3.32%	3.58%	4.61%	3.38%
U.S. Roads	Rural	28.92%	27.32%	32.70%	26.40%	26.70%	28.41%
	Urban	5.52%	7.27%	5.69%	5.15%	8.25%	6.37%
State Roads	Rural	45.70%	42.61%	40.52%	47.87%	42.48%	43.83%
	Urban	4.42%	5.26%	4.98%	4.70%	4.37%	4.74%
Total		100%	100%	100%	100%	100%	100%

Table 4.13. Average Distribution of All Speed Related Crashes

Highway Class		1991	1992	1993	1994	1995	Average
		Percentage					
Interstates	Rural	24.68%	23.73%	24.81%	25.27%	29.75%	25.65%
	Urban	14.49%	14.22%	15.08%	19.29%	12.91%	15.20%
U.S. Roads	Rural	16.94%	14.82%	16.15%	14.39%	15.40%	15.54%
	Urban	8.09%	10.03%	10.45%	10.03%	7.20%	9.16%
State Roads	Rural	31.15%	31.10%	28.44%	25.36%	30.59%	29.33%
	Urban	4.66%	6.10%	5.07%	5.66%	4.15%	5.13%
Total		100%	100%	100%	100%	100%	100%

Table 4.14. Average Distribution of Speed Related Fatal Crashes

Highway Class		1991	1992	1993	1994	1995	Average
		Percentage					
Interstates	Rural	25.00%	16.67%	15.00%	8.06%	20.75%	17.10%
	Urban	0.00%	0.00%	8.33%	8.06%	13.21%	5.92%
U.S. Roads	Rural	21.15%	20.00%	26.67%	27.42%	18.87%	22.82%
	Urban	5.77%	3.33%	5.00%	4.84%	5.66%	4.92%
State Roads	Rural	46.15%	56.67%	43.33%	43.55%	37.74%	45.49%
	Urban	1.92%	3.33%	1.67%	8.06%	3.77%	3.75%
Total		100%	100%	100%	100%	100%	100%

Table 4.15. Site Distribution Based on All Crashes

Highway Class		Percentage	Total Number	Number of Stations
Interstates	Rural	11.97%	6,695	5
	Urban	6.13%	3,437	2
U.S. Roads	Rural	18.81%	10,506	7
	Urban	14.52%	8,146	6
State Roads	Rural	33.61%	18,800	13
	Urban	14.96%	8,396	6
		100.00%	55,980	38

Table 4.16. Site Distribution by Fatal Crashes

Highway Class		Percentage	Total Number	Number of Stations
Interstates	Rural	13.26%	56	5
	Urban	3.38%	14	1
U.S. Roads	Rural	28.41%	121	11
	Urban	6.37%	27	2
State Roads	Rural	43.83%	187	17
	Urban	4.74%	20	2
		100.00%	427	38

Table 4.17. Site Distribution by Speed Related Crashes

Highway Class		Percentage	Total Number	Number of Stations
Interstates	Rural	25.65%	789	10
	Urban	15.20%	469	6
U.S. Roads	Rural	15.54%	476	6
	Urban	9.16%	281	3
State Roads	Rural	29.33%	894	11
	Urban	5.13%	157	2
		100.00%	3,065	38

Table 4.18. Site Distribution by Speed Related Fatal Crashes

Highway Class		Percentage	Total Number	Number of Stations
Interstates	Rural	17.10%	9	6
	Urban	5.92%	3	2
U.S. Roads	Rural	22.82%	12	9
	Urban	4.92%	3	2
State Roads	Rural	45.49%	23	17
	Urban	3.75%	2	1
		100.00%	51	38

4.8.3 Composite Site Distribution

4.8.3.1 Background

After obtaining six separate site distributions schemes, the next step was to combine them into a composite distribution. This was accomplished using the importance ratings provided by the Delphi study. A weighted average site distribution scheme was devised by multiplying the associated weights with the respective site distributions and summing them over each highway class.

The goal was to have a composite site distribution which statistically satisfied each of the site distribution criteria, meaning the proportion of sites in each highway class for each distribution criterion should be equal to the proportion of sites in each highway class for the composite distribution. However, this was a difficult task, as a major disparity in the number of sites by distribution criteria existed for Rural Interstates, Urban Interstates, and Rural State Roads. Because it would have been impossible to find a composite site distribution that statistically satisfied all three distribution criteria, the present study tried to satisfy the two most important site distribution criteria – DVMT and spatial distribution.

4.8.3.2 Statistical Methodology

An effort was made to obtain a composite site distribution by allocating monitoring stations to highway classes, which made the composite distribution statistically close to both the DVMT and spatial distribution. To quantify this composite distribution, it was tested for independence against the expected distributions for each criterion using Fisher's Exact Test (Everitt 1992) within SAS. An alternative method to Fisher's Exact

Test could be the use of a chi-squared table. However, the condition for using the chi-squared table was not met in the present study, because the expected number of sites was less than the minimum of 5, in some cases (Fienberg 1980).

4.8.3.3 Results

The proposed site distribution found by trial and error, was not significantly different from that based on either the DVMT or spatial distribution criteria, and had 13 stations in Rural Interstates, 10 in Urban Interstates, 7 in Rural US Roads, 2 in Urban US Roads, 4 in Rural State Roads, and 2 in Urban State Roads.

Table 4.19 compares the final site distribution to the expected DVMT distribution. From the probability-value associated with Fisher's Exact Test of 0.052, we can determine that the two distributions are dependent and not significantly different from each other. Table 4.20 compares the final site distribution to the expected spatial distribution. The probability value of 0.262 from the Fisher's Exact Test signifies that the final distribution is not significantly different from the expected spatial distribution. Finally Table 4.21 compares the final site distribution to the expected composite crash distribution. The probability value of 0.0001 from the Fisher's Exact Test indicates that the two distributions are significantly different from each other. This was expected, however, as the final site distribution was intended only to satisfy the DVMT and spatial distribution criteria.

Table 4.19. Comparison of Final Station Layout with DVMT Based Station Layout

Highway Class		DVMT	Number of Speed Stations Expected	Number of Speed Stations Actual
Interstates	Rural	20,469,678	15	13
	Urban	19,298,759	15	10
US Roads	Rural	5,320,672	4	7
	Urban	1,291,299	1	2
State Roads	Rural	2,906,413	2	4
	Urban	956,518	1	2
			Prob.	
Fisher's Exact Test (2-Tail)			0.052	

Table 4.20. Comparison of Final Station Layout With Spatial Distribution Based Station Layout

Highway Class		Lane Miles	Number of Speed Stations Expected	Number of Speed Stations Actual
Interstates	Rural	3,444	15	13
	Urban	1,508	7	10
US Roads	Rural	1,716	8	7
	Urban	277	1	2
State Roads	Rural	1,523	6	4
	Urban	196	1	2
			Prob.	
Fisher's Exact Test (2-Tail)			0.262	

Table 4.21. Comparison of Final Station Layout with Composite Crash Distribution Based Station Layout

Highway Class		Crashes	Number of Speed Stations	
			Expected	Actual
Interstates	Rural	1733	7	13
	Urban	837	3	10
US Roads	Rural	2077	8	7
	Urban	913	3	2
State Roads	Rural	3689	14	4
	Urban	750	3	2
			Prob.	
Fisher's Exact Test (2-Tail)			0.001	

4.9 Selection of Monitoring Locations

4.9.1 Background

It was decided that the proposed program should make maximum use of the existing speed monitoring, WIM, and ATR stations, without affecting the statistical reliability of the proposed monitoring plan. Three options were considered for this purpose, depending upon the level to which the existing stations will be utilized; minor, moderate, and major change.

The first option, minor change, tries to utilize existing stations if they are in the same district and highway class of the proposed station. In this option existing stations are given priority in the site selection process. If a certain highway class in an existing station is not available, a new site is randomly selected. The benefit to this method is

one of cost. Very few new stations will need to be installed. The main drawback is that it takes from the randomness of the site selection process.

The second option, moderate change, again tries to utilize existing stations, but in a different manner. The stations are first randomly selected. Then, existing stations are chosen if they match the characteristics of the randomly selected stations (i.e. DVMT, number of lanes, location, preferably the same continuous highway, etc.). This method will have a moderate cost, and a moderate degree of randomness.

The third option, major change, relies totally on random selection of sites. The benefit of this alternative is that sample segments will be completely random. The drawback is that of the high cost associated with installing new stations.

4.9.2 Selection Methodology

Given the final site distribution, discussed in Section 4.8.3.3, the next step is to select the monitoring location in an efficient manner.

4.9.2.1 Minor Change

To select the monitoring location for minor change an iterative procedure was developed to help allocate sites to highway classes within districts according to a range of plus or minus one of the recommended number of sites and based on the number of sites available. The recommended number of stations was computed by taking the percentage of lane miles in a given highway class for a given district and multiplying that number by the total number of stations in that highway class. This was done to ensure that sites would be distributed evenly throughout the state. The procedure minimized the difference between the actual and recommended stations per district and highway class.

Table 4.22. Minor Change Final Site Layout

District	Class		Speed Monitoring Stations Actual	Available
Laporte	Interstates	Rural	3	3
		Urban	2	3
	U.S. Roads	Rural	1	4
		Urban	1	2
	State Roads	Rural	0	1
		Urban	0	0
Fort Wayne	Interstates	Rural	3	4
		Urban	1	1
	U.S. Roads	Rural	2	4
		Urban	0	0
	State Roads	Rural	1	2
		Urban	0	0
Crawfordsville	Interstates	Rural	1	3
		Urban	1	1
	U.S. Roads	Rural	1	3
		Urban	1	1
	State Roads	Rural	1	4
		Urban	0	0
Greenfield	Interstates	Rural	1	1
		Urban	4	8
	U.S. Roads	Rural	1	2
		Urban	0	0
	State Roads	Rural	1	1
		Urban	0	1
Vincennes	Interstates	Rural	2	2
		Urban	1	1
	U.S. Roads	Rural	2	4
		Urban	0	0
	State Roads	Rural	0	2
		Urban	1	1
Seymour	Interstates	Rural	3	3
		Urban	1	2
	U.S. Roads	Rural	0	1
		Urban	0	0
	State Roads	Rural	1	3
		Urban	1	1

4.9.2.2 Moderate and Major Change

Moderate and Minor change will have the same number of stations in each district and highway class, the difference between the two methods is in how the highway segments for monitoring stations are selected. To allocate the monitoring locations for moderate and major change a similar iterative procedure used in minor change was followed, except that there was no constraint requiring the use of available stations. For moderate change the randomly selected stations were substituted for existing stations, if feasible. For major change, no such substitution took place. For this reason, the actual locations of individual monitoring stations will be different under moderate and major changes, even the distribution of stations remains the same.

4.9.2.3 Results

The number of stations in each highway class in each district for the minor change option is shown in Table 4.22. The final station location was determined for each district and highway class by randomly selecting among the available stations for that district and highway class. For example, there were four available U.S. Urban Roads in the Laporte district, but only one station was needed. That one station was chosen randomly among the four available stations. Based on the minor change option 38 existing stations will be used in the monitoring program. A table giving the exact segments in shown in Appendix A.

The number of stations in each highway class in each district for the moderate change option is shown in Table 4.23. The final station location was determined for each district and highway class by randomly selecting a highway segment from the HPMS database for the given district and highway class. After the segment had been selected, an effort was made to switch it with a segment, which contained a monitoring

station already. Based on the moderate change option 22 existing and 16 new stations would be used. A table giving the exact segments in shown in Appendix B.

The number of stations in each highway class in each district for the major change option is same as Table 4.23. The final station location was determined for each district and highway class by randomly selecting a highway segment from the HPMS database for the given district and highway class. Based on the major change option of the thirty-eight randomly selected segments 37 were new stations and only one happened to be an existing station. It was a coincidence that this existing station was randomly selected. A table giving the exact segments in shown in Appendix C.

Because the primary objective of the study was to utilize as many existing speed monitoring stations as possible, the present study recommends using the minor change option of 38 existing speed-monitoring stations.

4.10 Comparison of Proposed to Existing Site Layout

4.10.1 Statistical Methodology

A comparison of the proposed site layout to the existing site layout was done to see if the proposed site layout was an improvement over the existing program. The underlying assumption in the present study's sample size calculation was that the relative precision of the estimates would not exceed 2.0 mph. The relative precision can be calculated using the sample size and standard deviation of the percentage of vehicles exceeding the posted speed limit. The calculation of relative precisions for the existing program used data from existing sites. For the proposed program, the standard deviation of the percentage of vehicles exceeding the posted speed limit had to be estimated using historical data. This yielded a 95% confidence interval for the lower and upper bound of the standard deviation of the percentage of vehicles exceeding the posted

speed limit for use in calculating an upper and lower bound on the relative precision (Miller et al. 1990).

Table 4.23. Moderate and Major Final Site Layout

District	Highway Class		Speed Monitoring Stations Actual #
Laporte	Interstates	Rural	2
		Urban	2
	U.S. Roads	Rural	2
		Urban	0
	State Roads	Rural	0
		Urban	1
Fort Wayne	Interstates	Rural	2
		Urban	1
	U.S. Roads	Rural	2
		Urban	1
	State Roads	Rural	1
		Urban	0
Crawfordsville	Interstates	Rural	2
		Urban	0
	U.S. Roads	Rural	0
		Urban	1
	State Roads	Rural	1
		Urban	1
Greenfield	Interstates	Rural	2
		Urban	5
	U.S. Roads	Rural	0
		Urban	0
	State Roads	Rural	0
		Urban	0
Vincennes	Interstates	Rural	2
		Urban	1
	U.S. Roads	Rural	2
		Urban	0
	State Roads	Rural	1
		Urban	0
Seymour	Interstates	Rural	3
		Urban	1
	U.S. Roads	Rural	1
		Urban	0
	State Roads	Rural	1
		Urban	0

4.10.2 Results

Table 4.24 shows the proposed and existing site layouts with the expected number of stations for each site distribution criterion. The probability-values (P) underneath the expected values indicate the probability that the given site distribution will be independent of the listed site distribution criterion. A low P-value (<. 05) indicates significant evidence of independence.

From this table we can see that the proposed distribution is dependent on the DVMT and spatial criteria. This means that the proposed distribution is not significantly different from those distributions based on the DVMT and spatial criteria. The existing distribution, however, is only dependent on the crash criterion. In other words, the proposed station distribution satisfies two of the three distribution criteria while the existing site distribution only satisfies one distribution criterion.

Table 4.25 shows the relative precision of both the proposed and existing programs. For the proposed program a lower and upper confidence bound were calculated, because the standard deviation of the percentage of vehicles exceeding the posted speed limit was estimated using historical data. An upper and lower confidence bound was not necessary, however, for the existing program as it calculated the percentage of vehicles exceeding the posted speed limit directly using historical speed monitoring data. From this table it can be seen that the relative precision of both the proposed and existing site layouts fall below the limit of 2.0 for each distribution criterion. This means there is an adequate sample in each highway class for each criterion. Decreasing the total number of sampling stations from 46 to 38 was a concern to INDOT officials. The relative precision values below 2.0 for the proposed program indicate the proposed program will not sacrifice precision by decreasing the total number of stations.

Table 4.24. Comparison of Site Distributions for Existing and Proposed Programs, by Functional Class

	Actual Stations		Expected Number of Stations Based On		
	Proposed	Existing	DVMT	SITE	CRASH
Rural Interstates	13	8	15	15	6
Urban Interstates	10	7	14	6	4
Rural US Roads	7	15	5	8	7
Urban US Roads	2	3	1	2	3
Rural State Roads	4	12	2	6	15
Urban State Roads	2	1	1	1	3
Proposed	P-VALUE		0.052	0.2620	5.35E-05
Existing	P-VALUE		2.98E-10	9.15E-03	0.1140

Table 4.25. Comparison of Percent Error for Existing and Proposed Program, by Crash Type

	Existing Program	Proposed Program	
		Lower Bound	Upper Bound
DVMT	0.58	0.41	1.06
Spatial	0.54	0.41	1.06
Composite Crashes	0.75	0.63	1.42
All Crashes	0.72	0.67	1.53
All Fatal Crashes	0.87	0.71	1.60
Speed Crashes	0.64	0.53	1.23
Fatal Speed Crashes	0.88	0.70	1.58

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The present research has reviewed the existing speed monitoring program in Indiana from its inception in 1956 through the repeal of the NMSL in 1996, along with the speed-monitoring practices of the other 49 states. A survey of relevant agencies in Indiana indicated that Indiana should continue to monitor speeds under a formal program. Also, the present study analyzed the core components of the FHWA program and presented a new methodology to allocate speed monitoring stations based on three criteria, spatial distribution, DVMT distribution, and crash distribution. The present study evaluated three different approaches to select sampling locations throughout the state. Finally, the proposed station distribution was compared to the existing station distribution, and recommendations were made to modify the existing distribution to ensure consistency with FHWA guidelines.

The present study has shown the need for Indiana to continue a formal monitoring program. Furthermore, the present study used statistical models to show that mean speed does not vary by quarter, but the daily speed distributions do. As such Indiana may wish to monitor speeds every quarter. Furthermore, a statistical model was developed to test if mean speed varied by day of week and if it varied by direction of travel, the results indicated that day of week is not significant while direction of travel is. As such, Indiana should monitor speeds for a 24-hour period in both directions of travel. Also, a statistical model was developed which showed that speed varies by vehicle class. As such, Indiana should monitor speeds based on vehicle class. Finally, Indiana should

utilize the site layout shown in Figure 5.1 which incorporates 38 existing speed monitoring, WIM, and ATR stations.

5.2 Recommendations

It is the recommendation of this research that Indiana phase in the proposed speed monitoring plan developed in the present research. The implementation should include a visual inspection of all the WIM, ATR, and speed monitoring stations listed in Appendix A to ensure they are still capable of monitoring speeds by vehicle class and travel direction. If any problems should arise with the existing stations, that station should be substituted for another station within that district and highway class.

5.3 Implementation

According to FHWA recommendations, the philosophical approach to the development of a system that monitors traffic characteristics should follow the systems analysis concepts of holism and parsimony. Holism expresses the idea that the whole is much more than the sum of its parts, i.e., program integration is far superior to program separation. Parsimony is the quest for the simplest and most economical valid solution.

Against this background, the implementation of a speed monitoring system for the State of Indiana should ...

a) be built around the existing speed monitoring system into which the state has already invested a great deal of resources

b) ensure that resources, such as equipment and personnel can be used for more than one monitoring program

c) take advantage of current and potential versatility of equipment used in other programs that monitor traffic characteristics, such as the WIM and ATR stations

d) be such that any additional speed monitoring sites are installed only at candidate locations that do not have any existing WIM, ATR or speed monitoring station in their immediate vicinity.

Figure 5.1. Proposed Speed Monitoring Station Layout

LIST OF REFERENCES

Dalkey, N. C., Brown, B. B., and Cochran, S. (1969). The Delphi Method, Rand Corp., Santa Monica, Calif.

Dalkey, N. C. (1970). "Use of Self Ratings to Improve Group Estimates." Journal of Technological Forecasting and Social Change, 1(3).

Everitt, B. (1992). The Analysis of Contingency Tables, Chapman & Hall, London ; New York.

Federal Register (1993). Speed Monitoring Procedural Manual, Washington DC.

Fienberg, S. E. (1980). The Analysis of Cross-Classified Categorical Data, MIT Press, Cambridge, Mass.

Flora, J. O. D. a. J. (1982). "Alternative Measures of Restraint System Effectiveness: Interaction with Crash Severity Factors." SAE Technical Paper 820798, Society of Automotive Engineers, Warrandale, Pa.

Garber, N. G., R. (1991). Impact of Differential Speed Limits on Highway Speeds and Accidents, AAA Foundation for Traffic Safety, Washington, DC.

Institute of Transportation Engineers (ITE). (1976). Manual of Traffic Engineering Studies, ITE, Arlington, Va.

Jarman, R. (1956). "Traffic is a Monster." Saturday Evening Post, 41.

Jernigan, J. D. S., S.E.; Lynn, C.W. (1994). "Impact of the 65 MPH Speed Limit on Virginia's Rural Interstate Highways: 1989-1992." 9745-040-940, Virginia Transportation Research Council, Charlottesvlle, Virginia.

Martino, J. P. (1972). Technological Forecasting for Decision Making, , Amer. Elsevier.

McShane, W. R., and Roess, R. P. (1990). Traffic Engineering, Prentice-Hall, Englewood Cliffs, N.J.

Miller, I., Freund, J. E., and Johnson, R. A. (1990). Probability and Statistics for Engineers, Prentice Hall, Englewood Cliffs, N.J.

Montgomery, D. C. (1997). Design and Analysis of Experiments, Wiley, New York.

Sackman, H. (1974). Delphi Critique; Expert Opinion, Forecasting, and Group Process, Lexington Books, Lexington, Mass.

SAS Institute Inc. (1988). SAS/STAT User's Guide, Release 6.03 Edition, SAS Institute Inc., Crary, NC.

Solomon, D. (1964). Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle, FHWA, U.S. Department of Transportation.

U. S. DOT, (1975). Procedural Guide for Speed Monitoring, Federal Highway Administration, Office of Highway Planning, Washington DC.

U.S. DOT, (1978). Interim Speed Monitoring Procedures, Federal Highway Administration, Office of Highway Planning, Washington DC.

U.S. DOT, (1980). Speed Monitoring Program Procedural Manual, Federal Highway Administration, Office of Highway Planning, Washington DC.

U.S. DOT, (1992). Speed Monitoring Program Procedural Manual, Federal Highway Administration, Office of Highway Planning, Washington DC.

Vaa, T. (1997). "Increased Police Enforcement: Effects on Speed." Accident Analysis & Prevention, 29(3), 373-385.

APPENDIX A (CHARACTERISTICS OF CANDIDATE SEGMENTS)

Section ID	District	Class	Route	Rural/Urban	# Lanes	Station?
000070022570	Crawfordsville	I	I-70	Rural	4	Yes
000065174130	Crawfordsville	I	I 65	Rural	4	Yes
000074000000	Crawfordsville	I	I 74	Rural	4	Yes
000070007220	Crawfordsville	I	I 70	Urban	4	Yes
060034002000	Crawfordsville	SR	SR 32	Rural	2	Yes
840038502000	Crawfordsville	US	US 41	Urban	4	Yes
000069128720	Fort Wayne	I	I 69	Rural	4	Yes
000069051780	Fort Wayne	I	I 69	Rural	4	Yes
000069071550	Fort Wayne	I	I 69	Rural	4	Yes
000069109290	Fort Wayne	I	I 69	Urban	4	Yes
202006088200	Fort Wayne	US	US 6	Rural	2	Yes
520030002002	Fort Wayne	US	US 31	Rural	4	Yes
000070104560	Greenfield	I	I-70	Rural	4	Yes
000070103310	Greenfield	I	I-70	Urban	4	Yes
000065100650	Greenfield	I	I 65	Urban	6	Yes
000465017020	Greenfield	I	I-465	Urban	6	Yes
000070150670	Greenfield	I	I 70	Urban	4	Yes
330300250000	Greenfield	SR	SR 38	Rural	2	Yes
890100003000	Greenfield	US	US 27	Rural	2	Yes
000094032440	Laporte	I	I 94	Rural	6	Yes
000065249560	Laporte	I	I 65	Urban	4	Yes
000080004910	Laporte	I	I-80	Urban	6	Yes
647045902000	Laporte	US	US 30	Rural	4	Yes
661096002000	Laporte	US	US 421	Rural	2	Yes
710082002000	Laporte	US	US 20	Urban	4	Yes
000074168890	Seymour	I	I-74	Rural	4	Yes
000065041080	Seymour	I	I-65	Rural	4	Yes
000074148920	Seymour	I	I 74	Rural	4	Yes
000265000840	Seymour	I	I 265	Urban	4	Yes
880126002000	Seymour	SR	SR 56	Rural	2	Yes
530014002000	Seymour	SR	SR 37	Urban	4	Yes
150109002000	Seymour	US	US 50	Rural	4	Yes
000064027460	Vincennes	I	I 64	Rural	4	Yes
000064063720	Vincennes	I	I 64	Rural	4	Yes
000164000820	Vincennes	I	I 164	Urban	4	Yes
190135002000	Vincennes	SR	SR 56	Rural	2	Yes
820116002000	Vincennes	SR	SR 66	Urban	4	Yes
870130002000	Vincennes	US	US 231	Rural	2	Yes

APPENDIX B (CHARACTERISTICS OF CANDIDATE SEGMENTS)

Section ID	District	Class	Route	Rural/Urban	# Lanes	Station
000070022570	Crawfordsville	I	I-70	Rural	4	Yes
000465200000	Crawfordsville	I	I-465 2SEC	Rural	6	
550043252000	Crawfordsville	SR	SR 67	Rural	4	
830050902000	Crawfordsville	SR	SR 63	Urban	4	
670307902000	Crawfordsville	US	US 231	Urban	2	
000069128720	Fort Wayne	I	I 69	Rural	4	Yes
000469011570	Fort Wayne	I	I-469	Rural	4	
000069109290	Fort Wayne	I	I 69	Urban	4	
920490002001	Fort Wayne	SR	SR 114	Rural	2	Yes
022024158690	Fort Wayne	US	US 24	Rural	2	Yes
202006088200	Fort Wayne	US	US 6	Rural	2	Yes
010290002000	Fort Wayne	US	US 224	Urban	2	
000070104560	Greenfield	I	I-70	Rural	4	Yes
000074100260	Greenfield	I	I 74	Rural	2	
000070103310	Greenfield	I	I-70	Urban	4	
000065124170	Greenfield	I	I 65	Urban	4	
000465009320	Greenfield	I	I-465	Urban	6	Yes
000465017020	Greenfield	I	I-465	Urban	6	Yes
000465045270	Greenfield	I	I-465	Urban	6	Yes
000080025490	Laporte	I	I 80	Rural	4	Yes
000080043630	Laporte	I	I-80	Rural	4	
000080012930	Laporte	I	I 80	Urban	6	Yes
000080004910	Laporte	I	I-80	Urban	6	Yes
450535052000	Laporte	SR	SR 912	Urban	4	
080098002001	Laporte	US	US 421	Rural	2	Yes
500027102000	Laporte	US	US 31	Rural	4	
000065041080	Seymour	I	I-65	Rural	4	Yes
000074168890	Seymour	I	I-74	Rural	4	Yes
000074123110	Seymour	I	I 74	Rural	4	
000265000840	Seymour	I	I 265	Urban	4	Yes
880126002000	Seymour	SR	SR 56	Rural	2	Yes
150109002000	Seymour	US	US 50	Rural	4	Yes
000064027460	Vincennes	I	I 64	Rural	4	Yes
000064063720	Vincennes	I	I 64	Rural	4	Yes
190135002000	Vincennes	SR	SR 56	Rural	2	
140400002000	Vincennes	US	US 50	Rural	2	Yes
420059252000	Vincennes	US	US 50	Urban	4	
000164000820	Vincennes	I	I 164	Urban	4	Yes

APPENDIX C (CHARACTERISTICS OF CANDIDATE SEGMENTS)

Section ID	District	Class	Route	Rural/Urban	# Lanes	Station?
000070061420	Crawfordsville	I	I 70	Rural	4	
000465200000	Crawfordsville	I	I-465 2SEC	Rural	6	
060050752000	Crawfordsville	SR	SR 39	Urban	2	
790104302000	Crawfordsville	SR	SR 25	Rural	2	
540054902000	Crawfordsville	US	US 231	Rural	2	
000469011570	Fort Wayne	I	I-469	Rural	4	
000069059800	Fort Wayne	I	I-69	Rural	4	
020220002000	Fort Wayne	SR	SR 205	Rural	2	
020138552000	Fort Wayne	US	US 30	Rural	2	
200184002000	Fort Wayne	US	US 33	Rural	2	
020103152000	Fort Wayne	US	US 27	Urban	4	
020220002000	Fort Wayne	SR	SR 205	Rural	2	
000070104560	Greenfield	I	I-70	Rural	4	Yes
000069004900	Greenfield	I	I-69	Rural	6	
000069024050	Greenfield	I	I 69	Urban	4	
000065110230	Greenfield	I	I-65	Urban	6	
000070074530	Greenfield	I	I-70	Urban	6	
000465032870	Greenfield	I	I-465	Urban	6	
000065113150	Greenfield	I	I-65	Urban	6	
000080043630	Laporte	I	I-80	Rural	4	
000065246090	Laporte	I	I 65	Rural	4	
000094025000	Laporte	I	I 94	Urban	6	
000090013690	Laporte	I	I-90	Urban	4	
460250001000	Laporte	US	US 35	Rural	2	
750010002000	Laporte	US	US 30	Rural	4	
450535052000	Laporte	SR	SR 912	Urban	4	
000074123110	Seymour	I	I 74	Rural	4	
000275001270	Seymour	I	I-275	Rural	4	
000065058250	Seymour	I	I-65	Rural	4	
000265004380	Seymour	I	I 265	Urban	4	
030040602000	Seymour	US	US 31	Rural	4	
070017702000	Seymour	SR	SR 46	Rural	2	
000064017670	Vincennes	I	I 64	Rural	4	
000064029460	Vincennes	I	I 64	Rural	4	
000164000000	Vincennes	I	I-164	Urban	4	
140660002000	Vincennes	US	US 50	Rural	2	
740620002002	Vincennes	US	US 231	Rural	2	
770397002000	Vincennes	SR	SR 58	Rural	2	